Physics Units 1 & 2

Chapter 10 — Options: communicating physics, climate, nuclear and medical physics

Aboriginal and Torres Strait Islander content has been excluded as accuracy cannot be guaranteed, and it is better to be respectful than cover the entire curriculum inaccurately.

Significant effort has been made to ensure this content is legal. Please send any areas of concern to admin@vwx.au with appropriate document/legal references so errors can be verified and changes be made.

Contents

Chapter 10 Options: communicating physics, climate, nuclear and medical physics — 10A Communicating physics: evidence, sources and representations

Theory

From this chapter on, each student studies one **option** — a selected physics application such as the physics of climate change, of medical radiation, of flight or of musical sound. Unit 2 Area of Study 2 asks you to do more than learn that option's physics. Its outcome, verbatim from the study design: *"investigate and apply physics knowledge to develop and communicate an informed response to a contemporary societal issue or application related to a selected option"* (VCE Physics Study Design, Unit 2, Area of Study 2). Notice the words **develop and communicate**: the communication is not decoration added at the end. It is part of the outcome.

Printed identically under every one of the eighteen options is a shared block of key knowledge called **Communicating physics**. It is taught once, in this subtopic and the next, and every option subtopic (10C–13F) cross-references it. This subtopic owns the first three dot points, verbatim:

ID	Key knowledge (verbatim)
`U2.2.CP.1`	"evaluate validity of sources of information"
`U2.2.CP.2`	"apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations"
`U2.2.CP.3`	"apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations"

Subtopic 10B owns the remaining two: the influence of sociocultural, economic, legal and political factors, and the justification of a stance. Each option subtopic closes with an assessed **Option task**, and the marking rubric for every Option task is keyed to these five dot points — so the skills in this subtopic are assessed in whichever option you study. This subtopic also teaches three of the study design's key science skills for the first time: *"distinguish between opinion and evidence, and between scientific and non-scientific ideas"*; *"critically evaluate and interpret a range of scientific and media texts (including journal articles, mass media communications and opinions in the public domain), processes, claims and conclusions related to physics by considering the quality of available evidence"*; and *"discuss relevant physics information, ideas, concepts, theories and models and the connections between them"* (*VCE Physics Study Design, key science skills*).

Evidence, opinion and scientific ideas. A claim in physics must eventually answer to observation and measurement. That sentence contains the test you will use over and over in this subtopic.

Evidence is information — observations, measurements, data — that supports or challenges a claim. An **opinion** is what someone thinks or prefers. The two can sound identical when spoken aloud, so apply the test: *what observation or measurement could settle this claim?* If there is one, the claim is answerable by evidence. If there is none, you are looking at an opinion, a value or a preference — not because it is unimportant, but because no measurement can settle it.

A **scientific idea** is one that is built on evidence and that changes when the evidence changes. "The fission of one kilogram of uranium-235 releases about 8.2×10^{13} J" is a scientific claim: it follows from measured quantities and could be checked by measurement (4D). "Spent nuclear fuel remains radioactive for thousands of years" is also scientific: it follows from the measured half-lives of the isotopes present (3C).

A **non-scientific idea** is one that observation and measurement cannot settle. "Nuclear power stations are frightening" reports a feeling; it may be sincere, but no instrument can measure it true or false. "Australia should build nuclear power stations" is a decision — it needs physics as evidence, but it also involves cost, law and community values, which physics alone cannot settle. Non-scientific does not mean wrong or silly; it means *not the kind of question physics evidence can answer by itself*. The wider factors that enter such decisions are treated in 10B.

Beware also of claims that are *not yet* scientific: statements dressed as facts but offering no evidence, no mechanism and no way to check them — for example, that a jewellery item “blocks harmful energies”. If a claim is checkable in principle, ask for the check. If it is not checkable even in principle, it has no place in a physics argument.

Sources of information, and what makes them valid. In your option work you will lean heavily on information produced by other people. Two quick definitions: **primary data** are the data you generate yourself in an investigation and record in your logbook (14F); **secondary information** is what you collect from sources other people produced. The characteristics of primary data, and how to generate and record them, are taught in Chapter 14 (14B, 14E). Here the question is about secondary information: *how good is this source?*

A source is **valid** for a claim when it gives good grounds for accepting that claim. Validity is not a property of the source alone — a superb source can be quoted out of context, and a weak source can happen to be right — so you evaluate the source *and* the claim together. Six questions do most of the work:

1. **Expertise.** Who produced this, and is it their field? A radiation regulator writing about radiation dose is speaking in its field; a celebrity endorsing a health product is not.
2. **Independence.** Does the source gain anything if you believe the claim? A company describing its own product has an interest, and its claims need extra checking.
3. **Quality of evidence.** Does the source give data, methods, numbers with units — or only assertions? “Studies show…” without naming the studies is an assertion.
4. **Currency.** When was it produced? In fast-moving fields a ten-year-old figure may be wrong today, even if it was right then.
5. **Corroboration.** Do other, independent sources say the same thing? A claim confirmed by several sources with no connection to one another is far stronger than one standing alone.
6. **Transparency.** Does the source say where its own information came from, so you can check it?

Four kinds of source will meet you constantly, and they sit in different positions on this checklist:

- **Peer-reviewed journal articles.** Before a research article is published in a scientific journal, other experts in the field check its methods, data and reasoning — this is **peer review**. Peer review does not make an article certainly true, but it means the work has passed the scrutiny of people equipped to find its mistakes. Peer-reviewed articles are usually the strongest sources available.

- **Reports of government and scientific agencies.** In Australia these include ARPANSA, which regulates radiation and nuclear safety; CSIRO, the national science agency; the Bureau of Meteorology; Geoscience Australia; and ANSTO, which runs Australia’s nuclear research reactor OPAL and produces medical radioisotopes (3F, 4D). These agencies collect data systematically, name their methods, and publish with their reputation attached.

  Source: ARPANSA, Regulation of nuclear and radiation safety, retrieved 2026-08-18.

- **Media texts.** News reports, articles and broadcasts can carry good physics — but their job is to inform or persuade a general audience quickly, so they simplify, shorten and sometimes exaggerate. An opinion piece states its author’s position; treat it as opinion.

- **Opinions in the public domain.** Social media posts, comments and blogs: anyone can publish anything, and nothing is checked before it appears. Such a source can still *point* you to a claim worth investigating, but on its own it is the weakest evidence of all.

This book practises what it preaches: every real datum in it carries a source line naming the organisation, the document and the retrieval date — for example, the statement that Australia’s average temperature has risen by more than 1.5 °C since national records began in 1910 is drawn from the joint CSIRO and Bureau of Meteorology *State of the Climate* report (2D). When you write, do the same: name your sources and date them. The full conventions for acknowledging sources are taught in 14G.

Source: Bureau of Meteorology and CSIRO, State of the Climate 2024, retrieved 2026-08-18.

Checking claims against the physics you know. You have one checking tool that most readers of media texts do not have: a year or more of physics. When a claim contains numbers, units or physical reasoning, test it before you trust it.

- **Units.** Power and energy are different quantities with different units (5A): $1\,\mathrm{W} = 1\,\mathrm{J\ s^{-1}}$, and the kilowatt-hour is a unit of energy, not of power (5C). A media release that announces "a new solar farm will generate $100\,\mathrm{MW}$ of energy each year" has confused the two — megawatts measure power, the rate of energy transfer, not an amount of energy.
- **Orders of magnitude.** The wave equation $v = f\lambda$ (1A) lets you check any claim that links frequency and wavelength in a few seconds.
- **Established models.** All electromagnetic waves travel at the same speed c in a vacuum (1B). Any claim that one kind of light "travels slower because it has a lower frequency" fails at once.

A claim that fails a physics check is not valid, no matter how impressive its source looks. A claim that passes the physics check still needs a good source behind it. And remember that even authoritative sources can be out of date or wrong on a particular point — the checklist applies to the claim, not just to the name above it. Evaluating a claim this way — a scientific text, a media report or an opinion in the public domain, judged by the quality of the evidence behind it — is one of the key science skills this subtopic teaches, and it is exactly what the Option task's rubric rewards.

Definitions of key terms. A reader cannot follow a response whose key words are undefined, and a marker cannot reward one. Define terms before you use them. The trick is knowing which words need defining, and words are not all the same kind:

Kind of term	Examples	Behaviour
Measurable	mass, wavelength, half-life	one agreed definition; disputes are about measurement
Frame-dependent	down, left, now, here	precise once the frame is stated; ambiguous without it
Stipulated	a legal definition of "employee"	defined by an authority; another authority may define it differently
Contested	fairness, reliable, viable	competing definitions exist, and which you choose changes your conclusion
Response-reporting	beautiful, frightening	reports the speaker's reaction; sincere, but not settleable by measurement

Most of the big arguments in physics-and-society questions turn on **contested terms**. In 4D the word *viable* was treated exactly this way: two students can define it differently and both reason perfectly to opposite conclusions. When your response uses a contested term, do what 4D did: state the kind of term, give your working definition, state the frame you are using, and note that other definitions exist. In your own Option task, if you define a term differently from this book, say so — marking rewards the quality of the reasoning from the stated definition, not the definition chosen.

Three more reasoning tools belong here, because a definition on its own is not enough:

- **Audit the assumptions.** Questions smuggle claims into them. *"How do we solve X?"* assumes X exists, that X is a problem, that it is soluble, and that "we" are the right people to solve it. Before answering, list what the question already assumes — and answer that too.

- **The substitution test.** Before a describing word is allowed to carry the argument, swap it. If the argument survives the swap, the word was doing emotional work, not analytical work; if the argument genuinely changes, say what mechanism makes it change.
- **Steelman and symmetry.** Present each side of a debate in the strongest form its own advocates would recognise, then test both sides with the same tools. A substitution test applied to only one side is not rigour — it is advocacy wearing rigour's clothes. 4D puts all of this into practice on the nuclear energy question.

Scientific terminology, conventions and representations. Dot point CP.2 also requires that your response uses the language of physics correctly. By now the book has built that language; this is where you deploy it deliberately.

- **Terminology.** The study design's own terms are law in this subject (8C): the force due to gravity is F_g — the word "weight" is not used; the force between two surfaces in contact is the **normal force**, never "reaction force"; forces are labelled with the $F_{\text{on A by B}}$ convention, with $F_{\text{on A by B}} = -F_{\text{on B by A}}$. Using these correctly is assessed.
- **Numbers, units and symbols.** SI units, correct symbols, and the significant-figure rules of 1A apply to every number you write. State every quantity with its unit; convert before calculating; round consistently.
- **Graphs.** Labelled axes with the quantity and its unit, an appropriate linear scale, points plotted from the data, and a line or curve of best fit. Remember the study design's two graph rules (1A, 7B): not all graphs pass through the origin, and the origin is included as a data point only if it was authentically measured.
- **Representations.** Tables, graphs, force diagrams, ray diagrams, energy-flow diagrams, circuit diagrams, analogies and equations are all representations. Choose the one that fits the job and the audience, introduce it in your text, and make sure it is accurate. The full conventions of scientific report writing are taught in 14G.

Data representations, models and theories — and their limitations. Dot point CP.3 brings three ideas together.

Data representations organise observations. A table of raw readings is hard to argue from; the same readings plotted as a graph show a pattern at a glance — resistance from the gradient of an I–V graph (5D), motion from a velocity–time graph (7B). Choosing and constructing the right representation is itself part of the physics.

A **model** is a simplified picture used to reason about something that cannot be observed directly (5B). You have already worked with several: the wave model of light in Chapter 1, the water-circuit and delivery-van analogies for electric current (5B), the simple DC circuit model of a household electrical system (6B), and the simple kinetic energy model that explains why evaporation cools (2A). Every model is a tool, not the thing itself.

A **theory** is a broad, well-supported explanation that organises many observations and many predictions — the wave theory of light, for instance, organises reflection, refraction, dispersion and the behaviour of all electromagnetic radiation. Subtopic 14D examines the full distinction between an aim, a hypothesis, a model, a theory and a law; for this subtopic the working definitions above are what you need.

Limitations. Every model and every theory works within a domain and fails outside it. In the water-circuit analogy, cut a pipe and water pours out — but cut a wire and nothing spills, because the charge stays in the wire (5B); the simple DC model of a home says nothing about the fact that the real supply is alternating current (6B). Knowing where a model fails is part of understanding it (5B). In any response, then, do not just use a model or an explanation — say what it can account for and what it cannot. A stated limitation strengthens a response; a hidden one weakens it.

Connections. Finally, communicating physics is not listing facts — it is joining them. Compare these two sentences:

- "Optical fibres use total internal reflection."
- "Because light travelling from the fibre's core towards the boundary meets it at an angle greater than the critical angle, it is totally internally reflected (1C); because this happens again and again along the fibre, the light is guided around bends and carries the signal with it (1E)."

The second sentence earns its marks because the connections — *because*, *so*, *this means* — are explicit. When you discuss physics information, ideas, theories and models, make the links between them visible.

Putting it together. A response that satisfies CP.1–CP.3 does five things: it defines its key terms; it uses sources that survive the validity checklist, named and dated; it uses the study design's terminology, conventions and units correctly; it organises its evidence in the right representations; and it states the limitations of the models and explanations it uses. Subtopic 10B completes the picture with CP.4–CP.5 — the societal factors surrounding the issue and the justification of a stance — and every option subtopic from 10C to 13F closes with the assessed Option task, marked against a rubric built from these dot points.

Worked examples

Example 1 — scaffolded

A student researching sunburn risk in Australia finds two sources.

- **Source A.** The ARPANSA sun-protection page. ARPANSA is the Australian Government agency that regulates radiation and nuclear safety. The page publishes daily UV index forecasts for Australian locations and advises sun protection whenever the UV index is 3 or above, noting that clouds reduce UV radiation but do not block it, so sunburn is possible on cloudy days.
- **Source B.** An unsigned social media post: *"You can't get sunburnt on a cloudy day. The clouds block the UV."*

Evaluate the validity of each source for the question *"Can you get sunburnt on a cloudy day in Australia?"* and state which source the student should rely on.

Working	Comment
Source A — expertise: ARPANSA is the Australian Government agency responsible for radiation protection; UV radiation is exactly its field.	Expertise: the source is speaking in its own field.
Source A — independence: ARPANSA is a regulator, not a seller of sunscreen or clothing; it gains nothing from the reader's belief.	Independence: no commercial interest in the claim.
Source A — evidence: the page publishes daily measured UV index forecasts and states the conditions under which protection is needed.	Quality of evidence: data and a stated basis, not an assertion.
Source A — corroboration: the advice matches that of other Australian health bodies and the Bureau of Meteorology's UV observations.	Corroboration: independent sources agree.
Physics check: ultraviolet radiation is part of the electromagnetic spectrum (1B). Clouds absorb and scatter some of it, reducing the intensity, but they do not reduce it to zero — reduced is not blocked.	The claim is consistent with the physics you already know.
Source B — expertise, independence, evidence: no author is named, no qualifications are given, no data are offered, and no source for the claim is stated.	An unsigned post fails expertise, evidence and transparency at once.
Physics check: "the clouds block the UV" claims the intensity falls to zero behind cloud, which contradicts the observation that sunburn occurs on cloudy days.	The claim fails the physics check as well.
Conclusion: Source A is valid for this question; Source B is not. The student should rely on Source A.	Evaluate the source and the claim together.

Source: ARPANSA, UV index forecast, retrieved 2026-08-18.

Example 2 — scaffolded

Classify each statement about nuclear energy in Australia as **evidence or opinion**, and as **scientific or non-scientific**. Give the reason in each case.

(i) “The fission of one kilogram of uranium-235 releases about 8.2×10^{13} J.”
(ii) “Spent nuclear fuel remains radioactive for thousands of years.”
(iii) “Nuclear power stations are frightening.”
(iv) “Australia should build nuclear power stations.”

Statement	Evidence or opinion?	Scientific or non-scientific?	Reason
(i)	Evidence	Scientific	Follows from measured quantities (energy per fission, atoms per kilogram — 4D) and could be checked by measurement.
(ii)	Evidence	Scientific	Follows from measured half-lives of the isotopes in spent fuel (3C); a claim about a measurable quantity.
(iii)	Opinion	Non-scientific (response-reporting)	Reports a feeling. It may be sincere, but no measurement can settle whether it is “true”. It should be acknowledged as a feeling, not quoted as a fact.
(iv)	Opinion	Non-scientific (a decision)	Physics supplies evidence for the decision (energy per kilogram, emissions, build time), but the decision also involves cost, law and community values, which physics cannot settle (see 10B).

Notice that (iii) and (iv) are not silly or wrong — they are simply not the kind of statement physics evidence can settle. A good response says which kind of statement each claim is, and answers each kind appropriately.

Example 3 — unscaffolded

A blog post about radio broadcasting claims: *“ABC Radio Melbourne transmits at* 774 kHz*, which means its radio waves have a wavelength of about* 3.88 m*.”* The post names no author and gives no source for the number. Evaluate the claim and the source.

The claim can be checked directly with the wave equation (1A), since radio waves are electromagnetic waves and travel at $c = 3.00 \times 10^8$ m s^{-1} in air to an excellent approximation:

$$\lambda = \frac{v}{f} = \frac{3.00 \times 10^8}{7.74 \times 10^5} = \frac{3.00}{7.74} \times 10^{8-5} = 0.388 \times 10^3 = 388\,\text{m}$$

to three significant figures. The correct wavelength is 388 m, not 3.88 m — the blog’s value is too small by a factor of 100, as though the frequency were used in megahertz rather than kilohertz. (Check with the unrounded value: $f = v / \lambda = 3.00 \times 10^8 / 387.6 = 7.74 \times 10^5$ Hz. ✓)

The source fails the validity checklist as well: no author (expertise), no source for its number (transparency), and no corroboration offered. The claim fails the physics check, so it should be rejected no matter where it appeared. This is the value of knowing some physics: a reader with the wave equation can catch in seconds an error that an impressive-looking post cannot hide.

∴ the claim is not valid: the correct wavelength is $388\,\text{m}$, a factor of 100 larger than claimed, and the source is unsigned and unsourced.

Example 4 — unscaffolded

A student writes an explanation of household electricity for younger students, using the model from 6B: *"The electricity arriving at a home can be modelled as a simple DC circuit — a supply, wires, a fuse, switches, and the appliances connected in parallel."* (a) Explain what this model organises and helps the student explain. (b) Discuss two limitations of the model.

(a) The model organises several facts from Chapters 5 and 6 into one picture. The supply plays the role of the cell, providing the potential difference that drives a current around the circuit (5A). The fuse and switches sit in series with the supply, so they can protect or isolate the whole home (6B). The appliances are in parallel, which the model explains as the reason every appliance receives the full supply voltage and can operate independently of the others — exactly why household circuits are wired in parallel (6A). Energy transfer and power ($P = V\,I$) can be discussed appliance by appliance, and the energy used can be counted in kilowatt-hours (5C).

(b) Two limitations: first, the real household supply is alternating current — in Australia $230\,\text{V}$ at $50\,\text{Hz}$ — while the model uses direct current. The model therefore says nothing about what "alternating" means, about the frequency, or about why the grid uses AC rather than DC. Second, the simple model treats the connecting wires as perfect conductors with no resistance, whereas real wiring has resistance; anything in which the wires themselves matter cannot be reasoned about with this model. A good response that uses the model says so: the DC model is excellent for organising fuses, switches, parallel appliances and power, and it stops being useful the moment the question depends on the supply being AC.

∴ the model organises the supply–fuse–switch–appliance structure and the parallel wiring of a home; its limitations include that the real supply is $230\,\text{V}$, $50\,\text{Hz}$ AC, not DC, and that the wires are treated as having no resistance.

Practice questions

Question 1 (a) For each of the following, identify whether it is **primary** or **secondary** information for a student investigation: (i) readings of spring extension recorded in the student's own logbook; (ii) the ARPANSA daily UV index forecast for Melbourne; (iii) a peer-reviewed journal article reporting measurements of radiation dose; (iv) a newspaper opinion piece about energy policy; (v) a comment on a social media post; (vi) temperature records published by the Bureau of Meteorology. (b) The student's research question is *"How strong is the UV radiation in Melbourne today?"* Identify which one of (ii)–(vi) is the most valid source for this question, and justify your choice using two questions from the validity checklist.

Question 2 Classify each statement as **evidence or opinion**, and as **scientific or non-scientific**, giving a reason in each case: (i) "Gamma radiation has greater penetrating power than alpha radiation." (ii) "The half-life of caesium-137 is 30 years." (iii) "Living near a nuclear facility would worry me." (iv) "Coal-fired power stations should be closed as soon as possible."

Question 3 (a) Describe what peer review is, in two or three sentences. (b) Explain why a peer-reviewed journal article is generally a more valid source than a blog post making the same claim. (c) Explain why peer review does not make an article certainly true.

Question 4 A student writes: *"Renewable energy is obviously better than nuclear energy, so Australia should switch to it as fast as possible."* (a) Identify two terms in the sentence that need to be defined before the sentence can be evaluated, and state the kind of term each one is. (b) Give a working definition of one of them, stating the frame you are using, in the style of the contested-term box in 4D. (c) Explain why a marker cannot reward the student's sentence as written.

Question 5 A student writes: *"The book rests on the table because the table pushes up on the book with a reaction force that balances the book's weight."* (a) Identify two terms in the sentence that do not follow the study design's terminology conventions. (b) Rewrite the sentence using the correct terms. (c) State the condition, in the study design's force language, that makes the book remain at rest.

Question 6 Match each communication job below with the most appropriate representation from the list: *I–V graph; energy-flow diagram; force diagram with labelled forces*. Justify each choice in one sentence. (i) Show how the current in a resistor changes as the potential difference across it changes. (ii) Show the energy transformations in a battery-powered torch. (iii) Show the forces acting on a book resting on a table.

Question 7 A media release announces that *"a new solar farm will generate* $100\,\mathrm{MW}$ *of energy each year."* (a) Identify the physics error in the sentence. (b) Rewrite the sentence so that it is physically correct, in two different ways: one using a unit of power correctly, and one using a unit of energy correctly. (c) Explain why an error like this should reduce your confidence in the rest of the release.

Question 8 An online article claims: *"The infrared radiation from a heater travels more slowly than the visible light from a lamp, because infrared radiation has a lower frequency."* Evaluate this claim. In your answer, state what determines the speed of electromagnetic waves in air, and identify what frequency actually determines for an electromagnetic wave.

Question 9 Consider these two questions: A: *"How much energy is released by the complete fission of one kilogram of uranium-235?"* B: *"Should Australia use nuclear energy to generate electricity?"* (a) Identify which question physics alone can answer, and explain why. (b) Explain why physics alone cannot answer the other question, naming the kinds of factor that must also enter it. (Do not discuss those factors — that is the work of 10B.)

Question 10 In 2008 a newspaper columnist wrote: *"Wind and solar will never supply a meaningful share of Australia's electricity."* A student in 2026 finds this article while researching Australia's electricity generation. (a) Identify the question from the validity checklist that this source fails most seriously, and explain why. (b) State what the evidence now shows, with reference to the present Australian electricity mix described in 4D. (c) Explain why the currency of a source matters more in fast-moving fields than in slow ones.

Question 11 In 2A, evaporation was explained with a simple kinetic energy model: the fastest particles at the surface leave the liquid, taking energy with them, so the average kinetic energy — and hence the temperature — of what remains falls. (a) State what this model organises and explains. (b) Give one limitation of the model. (c) Explain why stating the limitation strengthens, rather than weakens, a response that uses the model.

Question 12 A friend says optical fibres are "just tubes that light bounces through". Write one short paragraph that corrects and improves this description, connecting the conditions for total internal reflection (1C) to the way light is guided along an optical fibre (1E). Your paragraph must make at least two explicit connections (use *because*, *so*, *this means*).

Question 13 A student proposes the investigation question: *"Why do Australians waste so much electricity?"* (a) Identify two assumptions built into the question. (b) Rewrite it as a question that physics investigation could actually answer.

Question 14 A company that sells rooftop solar panels publishes a leaflet claiming: *"A home with our panels draws no electricity from the grid — ever."* (a) Identify the question from the validity checklist this source fails, and explain why. (b) Explain whether the claim is checkable in principle, and describe the evidence that would be needed to support it.

Question 15 Consider the statement: *"All coal-fired power stations should be replaced by solar farms as soon as possible."* (a) Present the strongest case for the statement, in two or three sentences, using physics you have studied. (b) Present the strongest case against it, in two or three sentences, applying the same standard of evidence as in part (a). (c) Identify one piece of evidence that would help decide between the two cases.

Question 16 A student measures the current through a device for several potential differences and records:

Potential difference (V)	1.0	2.0	3.0	4.0	5.0
Current (A)	0.20	0.40	0.59	0.81	1.00

(a) Identify the most appropriate representation for these data, and justify your choice.
(b) State three conventions the representation must follow.
(c) Explain what the representation shows about the device, with reference to the ideas of 5D.
(d) Should the graph include the origin $(0,0)$ as a data point? Justify your answer using the study design's graph rules.

Question 17 A comment on a social media post reads: *"Medical X-rays are dangerous — radiation is involved, and any amount of radiation harms you."* (a) Classify the claim "any amount of radiation harms you" as scientific or non-scientific as it stands, and explain your reasoning. (b) Use the concepts of absorbed dose and equivalent dose from 3E to rewrite the claim as a scientific statement. (c) Identify one source that would be valid for the question *"How much radiation dose does a medical X-ray involve?"*, and justify your choice with two questions from the validity checklist.

Question 18 A student submits the following paragraph about nuclear energy:

> *"Nuclear energy is the best energy. It makes no pollution at all, and everyone agrees we need it. Australia should build reactors immediately."*

(a) Identify four weaknesses of this paragraph, drawing on the ideas of this subtopic and on 4D where relevant.
(b) Rewrite two sentences of the paragraph as claims that could be defended — with defined terms, supportable content and a named type of source.

Answers

Question 1 (a) (i) primary; (ii)–(vi) secondary; (b) source (ii) — see solution. **Question 2** (i) evidence, scientific; (ii) evidence, scientific; (iii) opinion, non-scientific (response-reporting); (iv) opinion, non-scientific (a decision). **Question 3** (a) see solution; (b) expertise, evidence and transparency are checked before publication; (c) reviewers can miss errors; results are later revised or replaced. **Question 4** (a) "better" — contested; "renewable" — stipulated/measurable (needs a definition in context); (b) see solution; (c) undefined contested term, no evidence, no frame. **Question 5** (a) "reaction force", "weight"; (b) see solution; (c) the forces on the book balance — the net force is zero. **Question 6** (i) I–V graph; (ii) energy-flow diagram; (iii) force diagram. **Question 7** (a) MW is a unit of power, not energy; (b) see solution; (c) see solution. **Question 8** The claim is incorrect — all electromagnetic waves travel at the same speed in air; see solution. **Question 9** (a) question A; (b) question B also involves cost, law and community values — see solution. **Question 10** (a) currency; (b) renewables now supply more than a third of Australia's electricity (4D); (c) see solution. **Question 11** (a) why evaporation cools, and why it happens at the surface; (b) e.g. says nothing about the rate of evaporation; (c) see solution. **Question 12** Rubric-style model paragraph in the fully-worked solutions. **Question 13** (a) e.g. that Australians waste electricity, and that "much" has a meaning; (b) see solution. **Question 14** (a) independence — the company profits from the claim; (b) yes — metered energy use over a full year; see solution. **Question 15** Rubric-style model answer in the fully-worked solutions. **Question 16** (a) a graph of current against potential difference; (b) see solution; (c) the device is ohmic, $R \approx 5.0\,\Omega$; (d) no — the origin was not measured. **Question 17** (a) non-scientific as stated — no dose, so nothing to measure; (b) see solution; (c) ARPANSA — see solution. **Question 18** (a) see solution — four weaknesses; (b) see solution.

Fully-worked solutions

Question 1 (a) Primary information is what the student generates and records themselves: only (i), the logbook readings, is primary. Everything produced by someone else — the ARPANSA forecast (ii), the journal article (iii), the opinion piece (iv), the social media comment (v) and the Bureau of Meteorology records (vi) — is secondary. (b) Source (ii), the ARPANSA UV index forecast for Melbourne. Justification using any two checklist questions, for example: **expertise** — ARPANSA is the Australian Government agency responsible for radiation protection, and UV radiation is its field; **currency** — the forecast is published daily, so it answers "today" directly; **corroboration** — its values can be checked against other Australian UV monitoring. The opinion piece (iv) and the comment (v) fail expertise and evidence for this question; the journal article (iii) and the temperature records (vi) are valid sources but answer different questions.

Question 2 (i) **Evidence, scientific.** Penetrating power is a measurable property, and the comparison between α and γ radiation is established from measurements (3B). A claim about what happens in the world, checkable by observation. (ii) **Evidence, scientific.** Half-life is a measurable quantity; 30 years is the measured half-life of caesium-137 (used as given in 4D). (iii) **Opinion, non-scientific (response-reporting).** It reports a feeling. It is not wrong — feelings are real — but no measurement can settle it, and it should be presented as a feeling, never quoted as a fact about radiation. (iv) **Opinion, non-scientific (a decision).** Physics provides evidence for the decision — energy per kilogram of fuel, life-cycle emissions (the emissions counted over a station's whole life, including building it, running it and dismantling it — the measure used in 4D), build time (4D) — but the decision also depends on cost, law and community values, which physics cannot settle. 10B treats those wider factors.

Question 3 A full-mark answer would include: (a) Before a research article is published in a scientific journal, other experts in the same field read it and check its methods, data and reasoning. They can demand corrections, further analysis, or reject the article. This process is called peer review. (b) A peer-reviewed article has passed scrutiny by people equipped to find its mistakes: its methods and data have been examined (quality of evidence), and the authors are identified and answerable to the journal (expertise and transparency). A blog post is checked by no one before publication. (c) Reviewers can miss errors, and science is provisional: later measurements or better methods can overturn an earlier result. Peer review raises confidence in a claim; it does not make the claim certainly true. That is why the validity checklist is applied to the claim itself, not only to the journal's name.

Question 4 A full-mark answer would include: (a) **"better"** — a contested term: competing definitions exist (cheaper? lower emissions? more reliable?), and the definition chosen changes the conclusion. **"renewable"** — a term that needs a stated definition in context (which sources count: wind, solar, hydroelectricity, and does nuclear count against it?). "Obviously" is also a warning word — it replaces the argument it should introduce. (b) Example, in the

4D style: *"In this response, 'better' means: able to supply the same electrical energy at lower life-cycle greenhouse emissions and at no greater cost. Other definitions exist — for example 'more reliable' or 'safer' — and are not interchangeable with this one."* Any clearly stated definition with an explicit frame earns the mark. (c) As written, the sentence cannot be evaluated: its key term is undefined and contested, so two readers can read two different claims into it; it offers no evidence; and it presents a decision ("should") as though physics alone settled it. Marking rewards reasoning from defined terms with stated evidence — none of which is present yet.

Question 5 A full-mark answer would include: (a) "reaction force" — the study design's term for the force in the normal direction between two surfaces in contact is the **normal force**; and "weight" — the force due to gravity is F_g, and the word "weight" is not used in this study (8C). (b) For example: *"The book rests on the table because the normal force of the table on the book, $F_{\text{on book by table}}$, balances the force due to gravity, $F_{\text{on book by Earth}} = mg$."* (c) The forces on the book balance: the net force on the book is zero. ($F_{\text{on book by table}}$ and $F_{\text{on book by Earth}}$ are equal in magnitude and opposite in direction; they are not a Newton's-third-law pair, since both act on the same object — the third-law partner of each acts on the other object.)

Question 6 (i) **I–V graph.** The job is to show how one quantity (current) changes as another (potential difference) is varied — exactly what a graph of current against potential difference displays (5D). (ii) **Energy-flow diagram.** The job is to show energy being transformed from one form to others (chemical → electrical → light and thermal), which an energy-flow diagram is built to display (6D). (iii) **Force diagram with labelled forces.** The job is to show the forces on one object, with magnitude and direction, using the $F_{\text{on A by B}}$ convention (8C).

Question 7 A full-mark answer would include: (a) The watt is a unit of **power** — the rate of energy transfer, $1\ \text{W} = 1\ \text{J s}^{-1}$ (5A). Energy is measured in joules or kilowatt-hours (5C). "Megawatts of energy" confuses the two quantities. (b) Power version: *"The new solar farm will have a generating capacity of* $100\ \text{MW}$*."* Energy version (with the basis stated): *"Running at its full* $100\ \text{MW}$ *for* $3000\ \text{h}$ *each year, the solar farm will generate* $3.0 \times 10^5\ \text{MW h}$ *— about* $1.1 \times 10^{15}\ \text{J}$ *— of energy each year."* Any energy unit used correctly, with a stated basis, earns the mark; the point is that the unit must be an energy unit (kW h, MW h, J), not a power unit. (c) The release's central claim mixes up two quantities that the study design defines separately. If the authors are careless with the quantities, their figures cannot be trusted without checking against an independent source — expertise, evidence and transparency all come into question.

Question 8 A full-mark answer would include:

- The claim is incorrect. All electromagnetic waves — radio, infrared, visible, ultraviolet, X-ray, gamma — are transverse waves that travel at the same speed c in a vacuum, and in air to an excellent approximation the same speed (1B). The heater's infrared and the lamp's visible light travel at the same speed through the room.
- Frequency does not set the speed. It is set by the source, and together with the (fixed) speed it determines the wavelength, $\lambda = v/f$ (1A, 1C): lower frequency means longer wavelength, not lower speed.
- The claim therefore fails the physics check and should not be repeated; the source of the article should be checked before any other claim from it is used.

Question 9 A full-mark answer would include: (a) **Question A** is answerable by physics alone. It has a single measurable answer: the energy released per fission multiplied by the number of atoms in a kilogram, about $8.2 \times 10^{13}\ \text{J}$ (4D). The inputs are measured quantities and the reasoning is calculation. (b) Question B is a decision, not a measurement. Physics supplies the evidence — energy per kilogram of fuel, life-cycle emissions, capacity factor, build time — but the answer also depends on factors physics cannot settle: cost, existing law (which currently prohibits nuclear power stations in Australia), and community values and preferences. These wider factors are the subject of 10B. A response that pretends physics alone answers question B is not wrong in its physics — it is wrong about what physics can do.

Question 10 A full-mark answer would include: (a) **Currency.** The article was written in 2008; by 2026 it is eighteen years old, and it describes a field — electricity generation — that has changed rapidly in exactly that period. Its prediction ("will never") has had time to be tested, and was made before much of the evidence now available existed. (b) As described in 4D, more than a third of Australia's electricity now comes from renewable sources (wind, solar and hydroelectricity). The columnist's prediction is contradicted by the present electricity mix, which is why the date of a source must be checked before it is used. (c) In a fast-moving field, data and technology change quickly, so an old statement can be false today even though it was reasonable when written. In a slow-moving field — the half-life of caesium-137, for example — a decades-old value can still be correct. Currency matters most where the subject itself is changing.

Question 11 A full-mark answer would include: (a) The model explains why evaporation cools a liquid: the fastest particles at the surface escape, taking their kinetic energy with them, so the average kinetic energy of the remaining particles falls, and with it the temperature (2A). It also organises why evaporation happens from the surface, and why moving air speeds cooling. (b) Any one limitation, clearly stated: the model says nothing about the *rate* of evaporation; it does not account for humidity or wind; it treats particles as tiny balls and ignores the forces between them; it does not explain boiling. (c) Stating a limitation shows the student knows the domain of the model — where it works and where it stops working — which is part of understanding it (5B). It also protects the response: a reader who finds the limitation themselves loses trust in the whole argument, while a stated limitation leaves the rest of the reasoning intact.

Question 12 Model paragraph (any version with the physics correct and the connections explicit):

"Light is not just bouncing down an empty tube. An optical fibre has a core surrounded by a material of lower refractive index, **so** light travelling in the core meets the boundary at angles greater than the critical angle. **Because** the angle is greater than the critical angle, the light is totally internally reflected rather than refracted out (1C). **This means** the light is reflected again and again along the fibre, even around gentle bends, **so** the signal it carries travels from one end to the other with little loss (1E)."

The physics required: the core–boundary arrangement, the critical angle as the condition, total internal reflection as the mechanism, and guided transmission as the consequence — with at least two explicit connecting words.

Question 13 A full-mark answer would include: (a) Any two, clearly stated: that Australians *do* waste electricity (asserted, not shown); that "much" has an agreed meaning (it is undefined — compared with whom, or what standard?); that the cause is a single "why" waiting to be found; that "Australians" behave as one group. (b) Any rewrite that physics investigation could answer, for example: *"What fraction of the electrical energy supplied to an incandescent globe is transformed into light?"* or *"How does the electrical energy used per household per year compare between two Victorian towns?"* The rewritten question must be measurable and must not assume its own answer.

Question 14 A full-mark answer would include: (a) **Independence.** The company profits from the claim being believed — it sells the panels — so it is not an independent witness, and the claim needs extra checking. (Transparency also fails: no measurements, no conditions, no data source are given.) (b) The claim is checkable in principle: the energy drawn from the grid is a measurable quantity (the household meter reads it, in kilowatt-hours — 5C). To support "no electricity from the grid, ever", the company would need metered records across a full year — including nights and cloudy periods, when the panels generate little or nothing — ideally checked by an independent body. The absolute word "ever" makes the claim very hard to support: one measured kilowatt-hour from the grid refutes it.

Question 15 Marks are awarded for the quality of the reasoning on both sides, not the conclusion reached. A full-mark answer would include: (a) Strongest case for: burning coal transfers carbon to the atmosphere as carbon dioxide, and electricity generation is Australia's largest single source of greenhouse emissions (4D), so replacing coal removes a large, ongoing emissions source. Solar generation produces no emissions while operating, its fuel is free, and Australia has world-class solar resources. (b) Strongest case against, held to the same standard: solar output is **variable** — it depends on the weather and the time of day, with a capacity factor well under half (4D) — while a coal station is dispatchable, so replacing coal with solar alone leaves the grid without power at night and in calm, cloudy weather unless storage or other sources are added, at additional cost. Build time, cost and the storage requirement must be part of the comparison, not assumed away. (c) Any one genuine deciding piece of evidence, for example: the cost per kilowatt-hour of solar-plus-storage compared with continued coal operation; measured capacity factors of Australian solar farms; the emissions the grid would actually save per year.

Question 16 A full-mark answer would include: (a) A graph of current (vertical axis) against potential difference (horizontal axis). The job is to show how current changes with potential difference — the I–V characteristic of the device (5D) — and a graph shows the pattern at a glance where the table shows only numbers. (b) Any three: axes labelled with the quantity and its unit; a linear scale using most of the grid; points plotted accurately from the table; a line (or curve) of best fit drawn, not dot-to-dot joining. (c) The points lie close to a straight line through the origin region: the current is (within small scatter) proportional to the potential difference, so the device is **ohmic**, with resistance $R = V / I \approx 5.0\,\Omega$ at every reading (5D). The small scatter is normal in real measurements; the line of best fit averages it out. (d) No. The student did not measure $0\,\mathrm{V}$ and $0\,\mathrm{A}$, and the study design's graph rule is that the origin may be included as a data point only if it was authentically measured. The line of best fit may be extended towards the origin, but $(0, 0)$ is not a data point here.

Question 17 A full-mark answer would include: (a) Non-scientific as stated — not because radiation is unreal, but because the claim names no quantity to measure. "Any amount" sweeps together doses that differ by factors of millions; without a dose there is nothing an investigation could measure or settle. It is also, in tone, response-reporting (fear) dressed as a fact. (b) A scientific version names the quantity: for example, *"A medical X-ray gives the patient an absorbed dose, measured in gray, and an equivalent dose, measured in sievert (3E); the effect of the radiation depends on that dose and on the duration of exposure."* The key move is replacing "any amount" with the measured dose — which is what 3E's dose quantities exist to do. The response must not claim small doses are harmless either — the point is that the claim is decided by the dose, which must be stated and measured. (c) ARPANSA — the Australian Government agency that regulates radiation safety (expertise: radiation protection is its field; independence: it is a regulator, not a seller of imaging services; transparency: it publishes its advice and the basis for it). Any two checklist questions, clearly applied, earn the mark.

Question 18 A full-mark answer would include: (a) Any four, clearly stated: - **"best" is a contested term** used without a definition — best by cost? emissions? reliability? The conclusion changes with the definition (4D's treatment of *viable* applies directly). - **"no pollution at all" is an absolute claim contradicted by evidence**: nuclear energy has low but non-zero life-cycle greenhouse emissions (about $12\,\mathrm{g}$ per $\mathrm{kW\,h}$ — 4D), and spent fuel remains radioactive (3C). "No … at all" and "everyone agrees" are slogans, not evidence. - **"everyone agrees" is an appeal to popularity**, not evidence; agreement is not measurement, and the claim is in any case false — the question is publicly contested (4D). - **"should … immediately" is a decision** presented as physics: it ignores cost, construction time and the present legal prohibitions (4D) — the wider factors belong to 10B, but even naming them shows the paragraph has skipped them. - **No sources, no definitions, no limitations** — the paragraph fails CP.1, CP.2 and CP.3 at once. (b) Any two defensible sentences, for example: *"I use 'better' to mean lower life-cycle greenhouse emissions per kilowatt-hour. Nuclear energy's life-cycle emissions are about* $12\,\mathrm{g}$ *of carbon dioxide equivalent per* $\mathrm{kW\,h}$*, far lower than coal's roughly* $820\,\mathrm{g}$ *per* $\mathrm{kW\,h}$ *(Source: IPCC, Fifth Assessment Report, Working Group III, Annex III, as cited in 4D)."* Marks are awarded for a defined term, a supportable (not absolute) claim, and a named source or source type — not for the conclusion reached.

Scope — *VCE Physics Study Design, Unit 2, Area of Study 2, Communicating physics* (the block printed under every option): "discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application" (`U2.2.CP.4`) · "apply physics understanding to justify a stance, opinion or solution to the selected issue or application" (`U2.2.CP.5`).

Theory

What this subtopic is for. In 10A you built the first half of communicating physics: evaluating the validity of sources, using physics terminology, conventions and representations correctly, and discussing what models and theories can and cannot explain. This subtopic is the second half. It teaches you to do two things that every Unit 2 option asks of you: to place a physics issue in its **societal context**, and to take a **stance** on it — a position, an opinion or a proposed solution — and **justify** that stance, which means giving the reasons and evidence for it so that someone else can test them.

The two dot points in the Scope note above are the study design's shared **Communicating physics** block. The study design prints this block identically under every one of the eighteen Unit 2 Area of Study 2 options. Whichever option your class studies — climate change (10C), fusion and fission (10D), medical radiation (10E), or any of the options in Chapters 11–13 — the same two requirements apply. The block is therefore taught once, here, and every option subtopic cross-references it. (One recorded wording difference: under Option 2.13 the fifth dot point prints as *"use physics understanding to justify a stance…"*, where the other seventeen options print *"apply physics understanding to justify a stance…"*. The expectation is the same either way.)

This subtopic also teaches two of the study design's key science skills for the first time: *"discuss the implications of research findings"* and *"analyse and evaluate physics-related societal issues taking into account the influence of social, economic, legal and political factors relevant to the selected issue"* (*VCE Physics Study Design, key science skills*).

You have already met this method at work. In 4D the question *"Is nuclear energy viable for Australia?"* was answered by gathering sourced evidence, presenting the strongest case on each side, and reaching a reasoned conclusion. Here the method itself becomes the subject.

Physics answers half the question. Some things about a physics issue are **measurable**: the half-life of caesium-137 is 30 years, the energy released by the fission of $1.0\,\text{kg}$ of uranium-235 is about 8.2×10^{13} J, and no amount of public debate changes either number. Other things about the same issue are **decisions**: where spent fuel should be stored, who should pay for it, and whether a country should build reactors at all. Decisions like these are not settled by measurement alone, because they involve what people value as well as what nature does.

The study design says this directly. One of its aims is that students *"develop an understanding of the cooperative, cumulative, iterative and interdisciplinary nature of science as a human endeavour, including its possibilities, limitations and sociocultural, economic, political and legal influences and consequences"*, and another is that they *"develop an informed and critical perspective, as local and global citizens, on contemporary science-based issues"* (*VCE Physics Study Design, aims of this study*). Physics tells you what is possible, what it costs in energy and materials, and what will happen if a choice is made. It does not, by itself, tell you what is fair, who should pay, or what the law should be. A complete response to a physics-in-society question therefore needs two halves: your physics understanding (which `U2.2.CP.5` demands), and the societal setting in which the physics sits (which `U2.2.CP.4` demands).

The four kinds of factor. `U2.2.CP.4` names four kinds of factor: **sociocultural**, **economic**, **legal** and **political**. Each is a lens — a way of sorting the things that shape an issue besides the physics. For each lens, the table gives the question it asks and examples drawn from earlier chapters of this book.

Factor	What it concerns	Guiding questions
Sociocultural	People and communities: how they live and work, their health, their	Who is affected? Who gains the benefits and who carries the risks?

Factor	What it concerns	Guiding questions
	beliefs, their trust, and what they value	What do the affected communities value, and what do they trust?
Economic	Money, work, prices and markets: costs, funding, jobs, and who pays versus who gains	What does it cost, and who pays? What does it return, and to whom? How does it affect jobs, prices and investment?
Legal	The rules in force: Acts of parliament, regulations, standards, regulators and treaties	What do the laws and standards require, allow or forbid? Who enforces them? What would have to change for the rules to change?
Political	How collective decisions get made: governments, parliaments, parties, elections, inquiries and pressure from interest groups	Who decides, and how? What do they need — votes, support, agreements? What have they promised or committed to?

Examples from this book:

- *Sociocultural.* A town's attitude to a proposed reactor near it; the health of patients treated with medical radioisotopes (3F); the fear some people feel about radiation of any kind (3E); the future of a region whose jobs are tied to an existing industry, such as the Latrobe Valley towns that depend on brown-coal power stations (4D).
- *Economic.* The cost of building new electricity generation compared with the alternatives — the CSIRO–AEMO GenCost studies estimate that new nuclear energy would cost more than new wind or solar generation together with the storage needed to make it dependable (4D); the price of electrical energy on a household bill, measured in kW h (5C).
- *Legal.* Section 140A of the *Environment Protection and Biodiversity Conservation Act 1999* (Cth), which prevents the Commonwealth Minister from approving the construction or operation of a nuclear power station in Australia; Victoria's *Nuclear Activities (Prohibitions) Act 1983* (Vic.); the *Climate Change Act 2022* (Cth), which writes Australia's emissions targets into law; the *Electricity Safety Act 1998* (Vic.) and the wiring standard AS/NZS 3000, which govern household electrical work (6B); and ARPANSA, the national body that regulates radiation safety (4D).
- *Political.* The 2019 inquiry of the federal House of Representatives Standing Committee on Industry, Science and Technology, which recommended lifting the nuclear prohibition — a recommendation the government of the day did not adopt (4D); government emissions targets, which begin as political commitments before becoming law.

Source: Australian Government, Environment Protection and Biodiversity Conservation Act 1999 (Cth) s 140A, retrieved 2026-08-24. Source: Parliament of Victoria, Nuclear Activities (Prohibitions) Act 1983 (Vic.), retrieved 2026-08-18. Source: Australian Government, Climate Change Act 2022 (Cth), retrieved 2026-08-18. Source: Parliament of Victoria, Electricity Safety Act 1998 (Vic.), retrieved 2026-08-18. Source: Standards Australia, AS/NZS 3000 Wiring Rules, retrieved 2026-08-18. Source: House of Representatives Standing Committee on Industry, Science and Technology, Not without your approval: Options, challenges and opportunities for Australia regarding the development of nuclear energy, 2019, retrieved 2026-08-18. Source: CSIRO and AEMO, GenCost 2023-24, retrieved 2026-08-18.

The categories overlap — and that is the point. A single fact can sit in more than one category. A government emissions target is *political* as a promise and *legal* once it is written into an Act. A power station closing is an *economic* event for its owner and a *sociocultural* event for its town. Classifying a factor is not a marking ritual; it is a checklist that stops you forgetting a whole lens. Before you finish discussing an issue, check: have I said something about how people are affected, about money, about the rules, and about who decides? Notice too what the four categories are *not*: physics facts themselves — half-lives, efficiencies, energy densities — are none of the four. They are what `U2.2.CP.5` brings to the discussion, and they anchor it.

“Discuss the influence” is not a list. The dot point’s verb is *discuss*, and the noun is *influence*. A list names factors; a discussion says **how** each factor acts on the issue — what it makes more likely or less likely, easier or harder, cheaper or dearer — and what follows from that for the decision. A reliable pattern is: *name the factor → explain how it acts → state the consequence for the issue or its possible solutions.*

Compare these two responses to the same issue.

- *List:* “There is a law against nuclear power stations.”
- *Discussion:* “Section 140A of the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) prevents the Commonwealth Minister from approving the construction or operation of a nuclear power station in Australia. This legal factor shapes the issue directly: even if a company could pay for a station and a community would accept one, none can be built until parliament removes the prohibition from the law. Any nuclear option therefore adds a parliamentary decision — and years of new regulation — before construction could begin, which lengthens its timeline and raises its cost relative to alternatives that need no change to the law.”

The second response earns marks because it traces the factor’s *influence*, not just its existence. Factors also pull against each other — a legal factor may forbid what an economic factor favours — so discussing them means weighing them, not merely naming them in turn.

The implications of research findings. The key science skills ask you to *discuss the implications of research findings*. An **implication** is what follows from a finding — not the finding itself, but what it means once it is true. Implications run in two directions:

- *Outward, into action.* What should people, engineers, industry or government do differently if the finding holds? Who is affected, and how?
- *Forward, into research.* What does the finding make newly worth checking, measuring or studying next?

A worked pattern: state the finding → state what changes if it is true → say who is affected and what they should do → say what should be investigated next. A finding with no implications is rare; a discussion that stops at restating the finding is incomplete.

Justifying a stance. A **stance** is a stated position on an issue: for, against, or conditional (“yes, but only if…”). An **opinion** is a view someone holds; it becomes part of a justified stance once reasons and evidence are attached to it. A **solution** is a stance in the shape of a proposal: here is what should be done, and here is why it is better than the alternatives. To **justify** any of these is to show your working — the same idea as in a calculation, applied to an argument.

The house method has eight steps. You practised all of them in 4D; here they are named.

1. **Define the key terms and state your frame.** If the issue contains a contested term — *viable*, *safe*, *sustainable* — say whose definition you are using (4D). Two students can answer opposite sides of the same question simply because they defined the word differently.
2. **Surface the assumptions.** Questions carry hidden claims inside them (*“How do we stop X?”* assumes X exists, that it is a problem, and that it can be stopped). Name the assumptions before you answer.
3. **Bring the physics.** State what the evidence, the measurements and the models say. This is the step that makes your response a *physics* response.
4. **Make the other side’s case at its strongest.** Present the strongest case against your position — in the form its own advocates would recognise — not a weak version set up to be knocked down.
5. **Test both sides the same way.** Apply your tests symmetrically. Where a claim leans on a single key word or on a comparison, use the substitution test you met in 4D: swap the key term and see whether the argument still stands.
6. **Weigh the four factors.** Bring in the sociocultural, economic, legal and political factors — not as a list, but as influences, each traced to its consequence.
7. **State your stance.** Say plainly what you conclude, including any conditions on it.
8. **Acknowledge the limits.** Say what your conclusion depends on, and what new evidence would change your mind.

Two ground rules sit under the method. First, distinguish opinion from evidence at every step — that is 10A's work, and it applies here unchanged. Second, **marks are awarded for the quality of the reasoning, not the conclusion reached**. A well-argued *for* and a well-argued *against* can both be full-mark responses; the marking guide rewards defined terms, surfaced assumptions, tested evidence and acknowledged limits, whatever side they serve.

How this section is assessed. Each option subtopic (10C–13F) closes with a house **Option task**: a 30-mark assessed piece in one of the study design's own Outcome 2 task formats — the formats include "a physics-referenced response to an issue", "a media analysis/response", "an infographic", "a scientific poster", "a report of an application of physics concepts to a real-world context" and "comparison and evaluation of two solutions to a problem…" (*VCE Physics Study Design, Unit 2, Outcome 2, suitable tasks for assessment*). Every one of those tasks is marked against a rubric keyed to the Communicating physics dot points, `U2.2.CP.1–.5`. The first three rows come from 10A; the last two — societal context, and justifying a stance — are this subtopic's. The conventions of reports and posters (terminology, units, significant figures, referencing) are 14G's. All assessment at Units 1 and 2 is school-based; nothing in this section contributes to a study score (see the front matter).

Worked examples

Example 1 — scaffolded

The nuclear energy issue of 4D produced many claims. Classify each of the following statements as **sociocultural**, **economic**, **legal** or **political**. If a statement fits more than one category, name the categories and say which is primary. If it fits none, say why.

(a) "Section 140A of the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) prevents the Commonwealth Minister from approving the construction or operation of nuclear power stations in Australia."
(b) "Australian cost studies estimate that new nuclear energy would cost more than new wind or solar generation together with storage."
(c) "Residents of a coastal town form an action group opposing a proposed reactor, citing health concerns and the effect on property prices."
(d) "A 2019 federal parliamentary inquiry recommended lifting the nuclear prohibition, but the government did not adopt the recommendation."
(e) "The complete fission of $1.0\,\text{kg}$ of uranium-235 releases about $8.2 \times 10^{13}\,\text{J}$."
(f) "The Latrobe Valley's brown-coal power stations provide work for many hundreds of people, and many more local jobs depend on them."

Working	Comment
(a) **Legal.** The statement names an Act of parliament in force.	The factor is a rule: it forbids something, and it is enforced by law. Its origin in politics does not change its present character as law.
(b) **Economic.** The statement is about the cost of building generation.	Cost comparisons are the economic lens: what something costs, and against what alternatives.
(c) **Sociocultural, with an economic strand.** The health concerns and community action are sociocultural; property prices are economic. Primary: sociocultural — the driver is what the community fears and values.	One real-world statement often touches two lenses. Classify by what drives it, and name the overlap.
(d) **Political.** An inquiry advises; a government decides. The statement is about that decision-making.	The recommendation itself changed nothing — the prohibition is still a *legal* factor. The story is about how (and whether) political decisions turn into legal change.
(e) **None of the four.** This is a physics fact.	Energy per fission is measurable and does not depend on society. It is the kind of fact `U2.2.CP.5` brings *into* the discussion; it is not a societal factor.
(f) **Both sociocultural and economic**, roughly equally.	Jobs and income are economic; what a closure does to a town's life is sociocultural. In a discussion, both halves earn their place.

Example 2 — scaffolded

Issue: *"Should every Victorian home have residual current devices (RCDs, or safety switches) on all of its electrical circuits, including older homes?"* The physics is in Chapter 6: an RCD detects an imbalance between the current leaving a circuit and the current returning, and breaks the circuit quickly, reducing the risk of electric shock (6E treats the device's operation and the danger thresholds for current through the body). For each of the four kinds of factor, state one influence on this issue.

Working	Comment
Physics anchor: an RCD breaks a faulty circuit quickly, before a dangerous current can persist through a person.	Physics says what the device can do. `U2.2.CP.4` asks what shapes whether it is actually installed.
Sociocultural: older homes were built before RCDs were common, so the homes with the least protection are often the ones least likely to gain it on their own; occupants may not know the risk, and renters cannot alter a switchboard themselves.	The influence: protection depends on awareness and on who controls the building, not just on the technology existing.
Economic: installing an RCD costs money — the device plus a licensed electrician — while the benefit is a reduced risk of death, injury and fire.	The influence: whoever weighs cost against risk (owner, landlord, tenant) decides how fast upgrades happen, and people on low incomes may defer them.
Legal: under the *Electricity Safety Act 1998* (Vic.), only a licensed person may do electrical installation work, and installations must follow AS/NZS 3000 (6B).	The influence: any rollout must go through licensed electricians to a set standard, and if governments want RCDs everywhere, the rules — not the physics — are what must change.
Political: governments can set requirements for new or rented homes and can run safety campaigns.	The influence: whether older homes are ever required to upgrade is a policy decision, made through parliaments and elections, not by engineers.

Each row does more than name a factor: it traces the factor's influence on the issue. That is the difference between a list and a discussion.

Example 3 — unscaffolded

A commentator claims: *"Australia should keep burning brown coal for electricity for as long as possible, because it is cheap."* Evaluate the claim and justify a stance, using the method of this subtopic. Draw on the sourced evidence of 4D.

Define the term and state the frame. "Cheap" is doing the work in this claim, and it is frame-dependent: cheap *for whom*? The running cost of an already-built brown-coal station is low for its operator, but the price of electricity to households, the cost of emissions to society, and the cost of replacing old stations are different measures. I take the claim in its strongest form: that continuing to run existing brown-coal stations is the lowest-cost course for Australia's electricity over the coming decades.

Surface the assumptions. The claim assumes that running cost is the only cost that matters, that emissions carry no cost, that the stations can keep running as long as wanted (they age), and that the alternatives are dearer.

Bring the physics. Brown coal releases about $10\,\mathrm{MJ\ kg^{-1}}$, and a brown-coal station converts only about one third of that thermal energy into electrical energy (4D). About $1.1\,\mathrm{t}$ of carbon dioxide is emitted per $\mathrm{MW\ h}$ generated — among the highest of any common fuel — and electricity generation is Australia's largest single source of greenhouse gas emissions, about one third of the national total (4D). The physics therefore says that every extra year of brown-coal generation adds a large, well-measured quantity of greenhouse gas.

The strongest case for the claim. It is genuine: the stations already exist, so their construction cost is long spent; Latrobe Valley coal is local and abundant; the stations supply a large share of Victoria's electricity around the clock; and many jobs and whole towns depend on them. On running cost alone, the claim has real support.

Weigh the four factors. **Legal:** the *Climate Change Act 2022* (Cth) commits Australia to emissions $43\,\%$ below 2005 levels by 2030 and to net zero by 2050 (4D); continued brown-coal generation at present scale is inconsistent with those targets, so the claim requires changing the law or ignoring it. **Economic:** the GenCost studies estimate that *new* wind and solar plus storage cost less than *new* fossil generation in Australia (4D) — the honest comparison is not old coal against nothing, but old coal against the cheaper alternatives now replacing it. **Political:** major parties and the electricity industry are planning closures and replacement; the claim runs against settled policy directions. **Sociocultural:** this is the claim's strongest lens — the Latrobe Valley's workers and towns carry the cost of any fast transition, and a just answer must include a plan for them.

State the stance. Against the claim, conditionally: Australia should not keep burning brown coal "for as long as possible", because the emissions physics, the law, and the cost of the alternatives all weigh against it — but the transition must be managed so that the Latrobe Valley's workers and communities are not left to carry its cost alone.

Acknowledge the limits. This conclusion depends on cost projections that change with method and time, on the present law, which parliament could change, and on the reliability of the replacement sources during the changeover. If storage proved far dearer than current studies estimate, the timing of closures would genuinely be reopened.

Example 4 — unscaffolded

More than one third of Australian homes now have a rooftop solar panel system.

Source: Clean Energy Regulator, Small-scale renewable energy scheme data, retrieved 2026-08-18.

Discuss the implications of this finding — outward, into action, and forward, into research.

The finding means that a large and growing share of Australia's homes are no longer only consumers of electrical energy: each is also a small generator, producing power in the middle of the day when the sun is out and drawing power from the grid at other times.

Outward — for householders. A home with rooftop solar transfers less energy from the grid in daylight hours, so the household's bill depends increasingly on *when* it uses energy, not only on how much (5C). The implication is practical: shifting loads such as hot water into sunny hours makes better use of the home's own generation.

Outward — for the electricity system. The grid must now supply the evening peak — when solar output falls and households switch on — rather than spread evenly across the day. The system's job changes from simply generating enough energy to balancing a moving pattern of supply and demand, which raises the value of storage and of flexible generation.

Outward — for policy. If more than one third of homes already generate, rules designed for one-way flow — household as consumer, grid as supplier — need review: how exported energy is paid for, and how the costs of maintaining the grid are shared between homes with panels and homes without.

Forward — into research. The finding invites questions: how does such a large fleet of household generators behave on cloudy days, season by season? What happens to the evening peak as the fraction of solar homes grows? These are investigation questions of exactly the kind Unit 2 Area of Study 3 asks you to design.

Practice questions

Question 1 `U2.2.CP.4` names four kinds of factor: sociocultural, economic, legal and political. (a) Copy the table below and complete it: for each factor, state what it concerns and one question that factor asks about an issue. (b) For each factor, give one example drawn from any earlier chapter of this book.

Factor	What it concerns	One guiding question	Example from this book
Sociocultural			
Economic			
Legal			
Political			

Question 2 Classify each statement as **sociocultural**, **economic**, **legal** or **political**. (a) "The *Climate Change Act 2022* (Cth) commits Australia to net zero emissions by 2050." (b) "Landholders receive yearly payments for hosting wind

turbines on their property.” (c) “Some people decline medical radioisotope treatment because they fear radiation.” (d) “A parliamentary committee holds an inquiry into Australia’s future electricity sources.” (e) “Australian cost studies estimate that new nuclear energy would cost more than new wind or solar generation with storage.”

Question 3 Consider the statement: *“Suppose the Victorian government announces a funded program to retrain Latrobe Valley power-station workers for jobs in new energy industries.”* (a) Identify which of the four factor categories this statement touches, and say what each contributes. (b) Explain why a factor belonging to two categories is not a problem for a discussion of influence.

Question 4 A student answering *“Discuss the factors affecting whether Australia builds nuclear power stations”* writes: *“Factors: it costs a lot. People worry about radiation. There is a law against it.”* (a) Explain why this response is a list rather than a discussion. (b) Rewrite one of the three points as a discussion, using the pattern *name the factor → explain how it acts → state the consequence*. (c) State the verb in `U2.2.CP.4`, and say what that verb requires beyond naming.

Question 5 More than one third of Australian homes now have a rooftop solar panel system (Clean Energy Regulator data). (a) State one implication of this finding for householders. (b) State one implication for the electricity system. (c) State one further question this finding raises that would be worth investigating.

Question 6 Below are four fragments from a student’s stance on the proposal *“All new homes in Victoria should be built with rooftop solar panels.”* Match each fragment to the step of the eight-step method (this subtopic) that it performs: (i) define the term and state the frame; (ii) surface the assumptions; (iii) make the other side’s case at its strongest; (iv) acknowledge the limits. (a) “The question assumes that a requirement, rather than a government payment or a recommendation, is the right instrument.” (b) “I take ‘should be built with’ to mean a building requirement applying to newly constructed homes, and I judge it by cost, emissions and reliability.” (c) “The strongest case against is that no requirement suits every block: a heavily shaded lot gains little, and the added upfront cost falls on first-home buyers.” (d) “If panel prices rise sharply, or household batteries become far cheaper, my conclusion would need to be reweighed.”

Question 7 A classmate says: *“The physics says fission of 1.0 kg of uranium-235 releases about* 8.2×10^{13} J *— roughly eight million times the energy of a kilogram of brown coal — so the debate about nuclear energy in Australia is settled.”* Use the method of this subtopic to evaluate the classmate’s claim.

Question 8 The Loy Yang power stations in Victoria’s Latrobe Valley burn brown coal and supply a large share of the state’s electricity. Analyse two sociocultural factors and two economic factors that would influence any decision to close these stations. For each factor, trace its influence, not just its existence.

Question 9 In 2019 a federal parliamentary inquiry recommended lifting the prohibition on nuclear power stations in Australia; as at 2026 the prohibition remains in force. (a) Distinguish the *political* elements of this story from the *legal* ones. (b) Explain why the distinction matters for a company deciding whether to invest in a proposed Australian nuclear power station.

Question 10 Choose the option subtopic (10C–13F) that your class studied. (a) State one societal issue or question raised by that option. (b) For your issue, give one sociocultural, one economic, one legal and one political factor. (c) State the physics understanding you would use to justify a stance on your issue.

Question 11 Before answering a question, audit its assumptions (4D). The question is: *“How should Australia stop climate change?”* State three claims embedded in the question that would need to be examined before it can be answered well, and for each say what evidence or physics is relevant. (The physics of climate change is treated in 2D and Option 2.1.)

Question 12 A hypothetical proposal: *“From 2035, every new vehicle sold in Australia must be a battery electric vehicle.”* (a) State the strongest case you can for the proposal. (b) State the strongest case you can against it. (c) Identify one physics concept relevant to the debate (for example, energy storage, charging power and time, or where the charging energy comes from), and say what it contributes.

Question 13 A social media post claims: *“Experts say Australia should close every coal-fired power station immediately. The science is settled.”* (a) State what you would need to check about the claim before accepting it. (b) Identify two societal factors the post ignores. (c) Rewrite the claim as a statement that could actually be tested.

Question 14 For each statement, decide whether it is an **opinion** (including a personal reaction) or a **justified stance** (a position with reasons and evidence attached), and give the reason for your classification. (a) “I don’t like the look of wind turbines.” (b) “Australian cost studies estimate new wind generation with storage costs less than new coal generation, so Australia should build wind rather than new coal.” (c) “Nuclear waste is frightening.” (d) “Because the hazard of some fission products is set by half-lives of thousands of years, a waste repository must isolate its contents on that timescale.” (e) State what would turn statement (a) into part of a reasoned discussion.

Question 15 A (hypothetical) survey finds that $80\,\%$ of Victorians support building more renewable generation, but $70\,\%$ oppose a large new solar farm being built within $10\,\mathrm{km}$ of their own home. (a) Discuss what this finding implies for planning new renewable generation. (b) Discuss what it implies for governments that have committed to emissions targets.

Question 16 A household considers installing a $5.0\,\mathrm{kW}$ rooftop solar system. On a clear day, assume the system produces its full rated power for $4.0\,\mathrm{h}$. (a) Use $P = E/t$ (5A) to calculate the energy the system produces on such a day, in $\mathrm{kW\,h}$. (b) The household uses $25\,\mathrm{kW\,h}$ per day. Calculate the fraction of its daily energy the clear-day production represents. (c) State two economic factors and one sociocultural factor the household should weigh. (d) Two neighbouring homes install identical systems. Explain why their savings can still differ.

Question 17 A commentator argues: *“Other countries have lowered their electricity emissions by building nuclear power stations, so Australia can too.”* (a) Apply a substitution test to this argument (4D). (b) Explain what the test shows: what does the argument establish, and what does it leave unsettled?

Question 18 Write a reasoned response justifying a stance on **one** of the following: (i) *“Australia should fund research into fusion energy, even though fusion cannot yet supply electricity.”* (ii) *“All new homes in Victoria should be built with rooftop solar panels.”* (iii) *“Hospitals should replace older radiation therapy equipment with newer models as soon as the newer models exist.”* Your response should define any contested terms and state your frame; use physics understanding; include at least one factor from each of the four `U2.2.CP.4` categories; address the strongest case on the other side; and acknowledge at least one limitation of your evidence.

Answers

Question 1 (a) See solution table; (b) any valid chapter-linked example per factor. **Question 2** (a) legal; (b) economic; (c) sociocultural; (d) political; (e) economic. **Question 3** (a) political (government decision and funding), economic (paid program, jobs), sociocultural (workers and town); (b) see solution — categories are lenses, not boxes. **Question 4** (a) it names factors without tracing any influence; (b) see solution for the pattern; (c) *discuss* — requires how the factor acts and what follows. **Question 5** (a) bills depend on when energy is used; (b) the grid must balance a moving supply–demand pattern, including the evening peak; (c) e.g. how the evening peak changes as more homes add panels. **Question 6** (a) surface the assumptions; (b) define the term and state the frame; (c) make the other side's case at its strongest; (d) acknowledge the limits. **Question 7** See solution — physics settles what is possible; cost, law, time and community acceptance remain open, so the debate is not settled. **Question 8** See solution — two sociocultural and two economic factors, each traced to its influence. **Question 9** (a) the inquiry and its recommendation are political; the prohibition in the Act is legal; (b) see solution — investment needs legal change, not political sympathy. **Question 10** Answer depends on the option studied; see solution for the required shape. **Question 11** See solution — e.g. that climate change is happening, that "stop" is defined, that "Australia" is the right frame, that stopping is achievable; each with relevant evidence. **Question 12** See solution — any genuine strongest cases; physics e.g. battery storage, charging power $P = E / t$, grid sources. **Question 13** (a) who the "experts" are, what evidence they cite, whether the source is valid (10A); (b) any two of the four categories, e.g. economic and sociocultural; (c) see solution. **Question 14** (a) opinion (personal reaction); (b) justified stance; (c) opinion (personal reaction); (d) justified stance/evidence-based conclusion; (e) see solution — attach evidence about community views. **Question 15** (a) support in principle does not guarantee acceptance of specific sites; (b) targets need build rates that survive local opposition. **Question 16** (a) $20\,\text{kW h}$; (b) 0.80 ($80\,\%$); (c) see solution; (d) roof orientation, shading, and the household's own usage pattern. **Question 17** (a) e.g. substitute "wind farms" for "nuclear power stations" — same form; (b) it establishes physical possibility — that it has been done before — not cost, law, timing or that nuclear is the best option here. **Question 18** Rubric-style model answer in the fully-worked solutions.

Fully-worked solutions

Question 1 A full response should: (a) Complete the table along these lines (wording may vary):

Factor	What it concerns	One guiding question
Sociocultural	people and communities: health, work, beliefs, trust, what they value	Who is affected, who gains, and who carries the risk?
Economic	money, jobs, prices, markets: costs, funding, who pays and who gains	What does it cost, what does it return, and to whom?
Legal	rules in force: Acts, regulations, standards, regulators, treaties	What do the rules require, allow or forbid, and who enforces them?
Political	how decisions are made: governments, parliaments, elections, inquiries	Who decides, how, and what have they committed to?

(b) Any valid examples, for example: sociocultural — community concern about radiation (3E), medical radioisotope treatment (3F); economic — GenCost comparisons of generation cost (4D), household electricity bills in kW h (5C); legal — *Electricity Safety Act 1998* (Vic.) and AS/NZS 3000 (6B); political — the 2019 nuclear inquiry (4D).

Question 2 (a) **Legal** — an Act of parliament in force. (b) **Economic** — a payment, income and a market arrangement. (c) **Sociocultural** — people's beliefs and feelings about a technology. (d) **Political** — the machinery by which a collective decision is prepared. (e) **Economic** — a comparison of costs.

Question 3 A full response should: (a) Identify at least three lenses: **political** — a government announcing and funding a program is an exercise of decision-making; **economic** — the program is funded money aimed at jobs and income; **sociocultural** — its purpose is people: workers, their skills and their town's future. (b) Explain that the categories are lenses for making sure nothing is missed, not boxes that a fact must fit one at a time. A factor touching two categories simply has two influences to trace, which makes the discussion richer, not muddled. What earns marks is tracing the influence, whatever the label.

Question 4 A full response should: (a) Explain that the response names three factors but traces none of them: it never says *how* the cost acts, *what* the worry does to the issue, or *what* the law means for the decision. Naming is a list; tracing the influence is a discussion. (b) Any one point rewritten in the pattern *factor → how it acts → consequence*. For example: "Section 140A of the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) prevents the Commonwealth Minister from approving nuclear power stations (factor). The prohibition means that no station can be built until parliament removes it from the law, however much a company could pay or a community could accept it (how it acts). Any nuclear option therefore adds a parliamentary decision and years of regulation before construction, lengthening its timeline and raising its cost against alternatives that need no change to the law (consequence)." (c) The verb is *discuss*. It requires the influence of each factor to be traced — the mechanism and its consequence — not merely the factor's existence.

Question 5 A full response should: (a) Any one genuine implication for householders: bills depend more on *when* energy is used; exported energy earns a payment while imported energy is bought; households become participants in the electricity system, not just customers. (b) Any one implication for the system: supply now moves with the sun, so the grid must manage a changing pattern of supply and demand; the evening peak matters more; storage becomes more valuable. (c) Any one forward question: how does the evening peak change as the solar fraction grows? How do millions of small generators behave on cloudy days? What share of household energy is actually self-supplied, season by season?

Question 6 (a) Surfacing the assumptions (step 2) — it names a claim hidden inside the proposal. (b) Defining the term and stating the frame (step 1). (c) Making the other side's case at its strongest (step 4) — it presents the opposition's best case. (d) Acknowledging the limits (step 8) — it says what would change the conclusion.

Question 7 A full response should: Agree with the physics and reject the conclusion drawn from it. The energy-density figure is correct: the fission of $1.0\,\mathrm{kg}$ of uranium-235 releases about 8.2×10^{13} J, roughly eight million times the energy released by burning a kilogram of brown coal (4D). But a physics fact settles only what is *possible*. The *debate* is about a decision, and decisions also involve the four factors: **economic** (Australian cost studies estimate new nuclear as the most expensive new generation option), **legal** (Commonwealth and Victorian law currently prohibit nuclear power stations), **political** (no government has adopted the 2019 inquiry's recommendation to lift the prohibition) and **sociocultural** (community acceptance, waste, workforce). The classmate has answered the physics half of the question — `U2.2.CP.5`'s material — and treated it as the whole question, which is exactly the gap `U2.2.CP.4` exists to fill. Energy density is a strong argument *within* the debate; it does not end the debate.

Question 8 A full response should give four factors, each traced to its influence. For example: *Sociocultural (1):* the Latrobe Valley's towns grew around the coal industry; closure affects workers' identities, family income and the region's services, so any decision carries a community cost that must be planned for (retraining, new industry), not just counted. *Sociocultural (2):* brown-coal generation is Australia's most emissions-intensive common electricity source, so its continuation affects everyone through climate change (2D); public concern about emissions therefore pressures the decision from outside the region. *Economic (1):* the stations employ many hundreds of people directly, and local businesses depend on that spending; closure removes that income from the region unless replacement work is found. *Economic (2):* the stations are old and will need expensive repairs or replacement anyway; since new wind and solar with storage are estimated to cost less than new fossil generation (GenCost, 4D), money spent keeping old coal running is money not spent on cheaper alternatives. (Any two genuine factors per category, each with its influence traced, earn the marks.)

Question 9 A full response should: (a) Distinguish the two: the inquiry, its work and its recommendation are **political** — advice produced by the parliamentary process; the prohibition itself is **legal** — a rule in force in an Act of parliament. A recommendation changes nothing until a parliament passes a law; the 2019 recommendation was not adopted, so the legal position did not move. (b) Explain the consequence for investment: a company cannot build on political sympathy alone. Investment needs the legal prohibition removed, a set of rules created for how such stations are built and run, and a regulator in place to enforce them — all of which take parliamentary action and years of process. A company weighing the risk must therefore treat "some politicians support nuclear energy" as far weaker than "the law permits nuclear energy". Confusing the political with the legal is a practical error, not just a classification one.

Question 10 The answer depends on the option studied; a full response has the right *shape*: (a) one clearly stated issue or question from the option (for Option 2.1: *"Should Australia reduce its greenhouse emissions faster than its current target?"*). (b) one factor per category, each relevant to that issue (e.g. for Option 2.1: sociocultural — health effects of a changed climate; economic — cost of changing energy sources; legal — the *Climate Change Act 2022* targets; political — international climate negotiations). (c) the physics of the option itself (e.g. for Option 2.1: how greenhouse gases absorb and re-emit infrared radiation, and the evidence for an enhanced greenhouse effect — the physics taught in that option subtopic).

Question 11 A full response should name three embedded claims and attach the relevant evidence to each. For example: - That climate change is happening and is human-influenced — examine the measured evidence for an enhanced greenhouse effect (2D, Option 2.1). - That "stop" is defined — halt further change, reverse change already present, or limit change to some level? Physics sets what each reading would require of emissions. - That "Australia" is the right frame — Australia's share of global emissions is what Australian action can affect; the question assumes national action is the unit to discuss. - That stopping is achievable — assumes technologies and policies exist that could bring emissions to the required level in time. (Any three, clearly stated with relevant evidence or physics attached, earn the marks.)

Question 12 A full response should give two genuinely strong cases and one physics concept. For example: (a) *For:* petrol and diesel vehicles turn most of their fuel's energy into waste heat; electric vehicles put a much larger fraction of their stored energy into motion. If the charging energy comes from low-emissions sources, transport emissions fall; and charging at home shifts demand to times when solar output is high. (b) *Against:* batteries store limited energy per kilogram, so long trips and heavy loads are harder; charging takes far longer than filling a fuel tank unless very high power is available ($P = E / t$); the electricity grid must grow to supply the extra energy; and vehicles, charging equipment and batteries have costs and materials that fall unevenly on different households. (c) Any one, applied: energy storage (chemical energy in batteries, capacity limits); charging power and time ($t = E / P$ — a $50\,\text{kW h}$ battery at $7\,\text{kW}$ takes hours, at $100\,\text{kW}$ far less); the source of the charging energy (the emissions depend on what generated the electricity, not on the vehicle itself).

Question 13 A full response should: (a) Check the source before the claim: who the "experts" are, whether they are named, what evidence they cite, and whether the source is one whose validity has been evaluated (10A). "Experts say" with no names and no evidence is not a usable source. (b) Any two of the four categories, traced: **economic** — closing every station at once would remove a large share of generation before replacements exist, affecting prices and supply; **sociocultural** — the workers and towns that depend on the stations; **legal** — contracts, energy-market rules and emissions law shape what "immediately" could even mean; **political** — no such decision could be made outside government processes. (c) For example: "Closing Australia's coal-fired power stations by a stated year would reduce electricity-sector emissions by a stated amount, at a stated cost, provided replacement generation of stated capacity is built in time." That version names quantities that can be checked, instead of asserting them as settled.

Question 14 A full response should: (a) **Opinion** — a personal reaction (how the speaker feels about an appearance); it reports a response and cannot be true or false in the way a claim can. (b) **Justified stance** — a position ("build wind rather than new coal") with a stated reason attached to citable evidence (the cost studies). (c) **Opinion** — again a personal reaction ("frightening"); it may be widely shared, but as stated it is a feeling, not an argument. (d) **Justified stance / evidence-based conclusion** — the position (isolate waste on thousand-year timescales) follows from stated physics (half-lives set the hazard timescale, 3C). (e) Statement (a) becomes part of a reasoned discussion when it is attached to evidence about community views — for example, survey data showing local opposition — and used as a sociocultural factor: what people value shapes whether a project proceeds, which is an influence worth discussing even though no physics changes.

Question 15 A full response should: (a) Discuss the gap between support in principle and acceptance in particular. The finding means planners cannot assume that general approval of renewables turns into approval of any specific site; the choice of site, its distance from homes, and the way local communities share in the benefits (for example, payments to landholders and local projects) become decisive influences on how fast generation can actually be built. (b) Discuss the consequence for governments: an emissions target is a commitment to a *quantity* of change by a *date*, and it is met only if enough generation is actually built. If local opposition slows building, governments must either find ways to make projects acceptable, or accept that the target is at risk. The finding is therefore a warning that targets and acceptance are two different problems, and solving one does not solve the other.

Question 16 (a) Rearranging $P = E / t$:

$$E = P\,t = 5.0\,\mathrm{kW} \times 4.0\,\mathrm{h} = 20\,\mathrm{kW\,h}\,.$$

(b) Fraction of daily use:

$$\frac{20}{25} = 0.80\,,$$

so on a clear day the system produces $80\,\%$ of the household's daily energy. (c) *Economic:* the upfront cost of the system and its installation; the reduction in the electricity bill (and the payment for exported energy); the system's lifetime versus the time taken to recover its cost. *Sociocultural:* the household's reasons (concern about emissions, independence from the grid), and what neighbours and the local community think of rooftop panels. (d) The energy a panel system captures depends on its situation: one roof may face the sun well while the other is partly shaded by a tree or neighbouring building. The households' own usage also differs — one may use much of its energy in sunny hours, the other mostly at night, buying its energy back from the grid. Same hardware, different physics of placement and different behaviour, different savings.

Question 17 A full response should: (a) Substitute the key term: *"Other countries have lowered their electricity emissions by building wind farms, so Australia can too."* The substituted argument has exactly the same form, and is equally plausible — which is the point of the test. (b) The test shows what the argument does and does not establish. It establishes **physical possibility — that it has been done**: other grids have in fact cut emissions with the technology named, so the claim is not fantasy. It does **not** establish that Australia *should* choose that technology: cost, construction time, the present legal position, community acceptance, and the alternatives available here are all unsettled by the argument's form, because the same form proves the same for any technology another country has used. The argument is a genuine piece of evidence — proof the outcome is achievable — but a weak basis for a conclusion, because it does no weighing.

Question 18 This is a reasoning task. Marks are awarded for the quality of the reasoning, not the conclusion reached; a well-argued *for*, *against* or *conditional* stance can all be excellent. A rubric-style model response to option (ii), arguing *for* with conditions, to show the form — the same structure serves the opposite conclusion:

Define the term and state the frame. "I take 'should be built with' to mean a building requirement applying to newly constructed homes, and I judge it as a policy question weighing cost, emissions and reliability — not as a claim about existing homes."

Bring the physics. "A $5.0\,\mathrm{kW}$ rooftop system at full output for $4.0\,\mathrm{h}$ produces $20\,\mathrm{kW\,h}$ of energy ($E = P\,t$), a substantial fraction of a typical household's day (Question 16). New homes have one advantage existing homes lack: their roof can be designed from the start to face the sun well and avoid shade, so a panel system added at build time captures more energy than the same panels added later to a poorly oriented roof."

Weigh the four factors. "**Economic:** panel prices have fallen for decades, and fitting panels during construction is cheaper than adding them later; the buyer pays once and the bill savings follow for the life of the system. **Sociocultural:** householders gain lower bills, and emissions fall with every solar home; the benefit also reaches renters, whose bills drop even though they did not choose the system. **Legal:** building requirements already shape how new homes are constructed, so a solar requirement fits an existing instrument. **Political:** governments with emissions targets need new homes — which will still be standing in 2050 — to add clean generation rather than demand for it."

The strongest case against. "The case against is genuine: no requirement suits every block — a heavily shaded or narrow lot gains little; the added upfront cost falls on first-home buyers, who are already stretched; and households with very small energy needs may never recover the cost. A blanket rule, critics argue, should at least allow exceptions."

Acknowledge the limits. "My conclusion depends on panel costs staying low and on the value of daytime generation remaining high; if batteries become far cheaper, the case for capturing one's own energy changes shape rather than disappearing."

Conclusion. "On the frame stated, I support the requirement conditionally: new homes should be built with rooftop solar panels, with an exception for blocks that clearly gain little — because build-time installation is the cheapest moment to add generation that the physics shows will capture energy for decades."

A response arguing *against* should use the same structure and the same honesty: define, bring the physics, weigh all four factors, present the strongest case *for* the requirement, and state what evidence would change the conclusion.

Chapter 10 Options: communicating physics, climate, nuclear and medical physics — 10C Option 2.1: How does physics explain climate change?

(The physics of climate change)

Theory

Radiation from the Sun to the Earth, and back out again. The Sun's surface is at about $5800\,\mathrm{K}$, and the radiation it emits is mainly ultraviolet, visible and infrared (1B), with its peak in the visible region (2C). This radiation crosses space and reaches the top of Earth's atmosphere. As it passes **through the atmosphere**, part of it is reflected straight back to space by clouds, particles and bright surfaces, and part is absorbed by the atmosphere itself. The remainder reaches the surface and is **absorbed by Earth**: the energy of the radiation is transformed into thermal energy of the land and ocean, and the surface warms (the energy transfers and transformations are treated in 2D).

A warm surface does not keep this energy. Like every object above absolute zero, Earth's surface continually **re-emits** energy as electromagnetic radiation (2C). But Earth is far cooler than the Sun — its mean surface temperature is about $288\,\mathrm{K}$ ($15\,°\mathrm{C}$) — and by Wien's Law the cooler the object, the longer the peak wavelength. So the radiation arriving from the Sun peaks in the visible, while the radiation re-emitted by Earth peaks deep in the infrared. This transformation of radiation — short-wavelength radiation in, long-wavelength infrared radiation out — is the starting point for the physics of climate.

The greenhouse effect. The atmosphere is not transparent to that outgoing infrared. Certain gases — the **greenhouse gases**, mainly water vapour, carbon dioxide (CO_2) and methane (CH_4) — **absorb** the infrared radiation emitted by the surface and **re-emit** it in all directions. A large share of the re-emitted radiation travels back downward and is absorbed by the surface again. The surface therefore receives energy twice: once from the Sun, and once from the atmosphere. The result is a warmer surface than the atmosphere-free case: with the greenhouse gases removed, Earth's mean surface temperature would be about $33\,°\mathrm{C}$ cooler — below the freezing point of water — instead of the observed $15\,°\mathrm{C}$. This natural warming is the **greenhouse effect**, and it is what makes Earth habitable.

Source: National Geographic Society, *Greenhouse Effect* (education resource, surface about $33\,°\mathrm{C}$ cooler without the greenhouse effect), retrieved 2026-08-18.

Global warming and the enhanced greenhouse effect. When human activity adds greenhouse gases to the atmosphere, the absorption and re-emission of outgoing infrared increases: more infrared is sent back to the surface, so the surface must warm until the energy it radiates to space once again balances the energy it receives. The **additional** warming on top of the natural greenhouse effect, caused by the human-added gases, is the **enhanced greenhouse effect**, and the rise in the mean surface temperature it produces is **global warming**. Two human influences appear in the study design's own wording:

- **the balance of gases in the atmosphere** — burning fossil fuels and clearing land have raised the CO_2 concentration from about $280\,\mathrm{ppm}$ (parts per million) before the industrial era to over $427\,\mathrm{ppm}$, and farming and fossil-fuel extraction have more than doubled the methane concentration;
- **the materials that comprise the surface of Earth** — clearing forest for darker farmland, building dark urban surfaces, and melting snow and ice all change the fraction of the incoming solar radiation that the surface reflects (its **albedo**) and the fraction it absorbs, changing how much solar energy is transformed into thermal energy at the surface (2D).

Comparing the radiation from the Sun and from Earth. The general comparison of the radiation from objects at different temperatures is taught in 2C: the hotter the object, the higher its radiation curve at every wavelength, the shorter its peak wavelength, and the greater the total energy it emits across the whole electromagnetic spectrum. Option 2.1 applies this to the Sun:

Object	Temperature T	λ_{max}	Region of spectrum
Surface of the Sun	$5800\,\mathrm{K}$	$500\,\mathrm{nm}$	visible
Mean surface of Earth	$288\,\mathrm{K}$ ($15\,°\mathrm{C}$)	$10\,\mu\mathrm{m}$	infrared

Because the Sun is so much hotter than Earth, the radiation arriving at Earth is concentrated at short (mostly visible and near-infrared) wavelengths, while the radiation Earth re-emits is concentrated at long (thermal infrared) wavelengths. This is why the atmosphere lets most of the incoming solar radiation pass, yet intercepts much of the outgoing radiation: the greenhouse gases absorb strongly at the long infrared wavelengths Earth emits, and only weakly at the short wavelengths the Sun sends.

Wien's Law applied to Earth's re-radiation. Wien's Law itself is taught in 2C: $\lambda_{max} T = 2.9 \times 10^{-3}$ m K. Here it is applied to the radiation re-emitted by Earth. For the mean surface temperature $T = 288\,\mathrm{K}$:

$$\lambda_{max} = \frac{2.9 \times 10^{-3}}{288} = 1.0 \times 10^{-5}\,\mathrm{m} = 10\,\mu\mathrm{m},$$

deep in the infrared — exactly the region the greenhouse gases absorb. If the surface warms, the peak wavelength becomes slightly shorter: a surface at $300\,\mathrm{K}$ re-emits with $\lambda_{max} = 9.7\,\mu\mathrm{m}$.

The Stefan–Boltzmann Law. The power P radiated by a body depends on its temperature according to the **Stefan–Boltzmann Law**, printed in the study design as

$$P \propto T^4,$$

with T the absolute temperature in kelvin. The fourth-power dependence makes the radiated power extremely sensitive to temperature: doubling the absolute temperature multiplies the radiated power by $2^4 = 16$; tripling it multiplies the power by $3^4 = 81$. For two temperatures T_1 and T_2 the powers compare as

$$\frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^4.$$

Two consequences matter for climate. First, per unit area the Sun's surface radiates enormously more power than Earth's surface — $(5800/288)^4 \approx 1.6 \times 10^5$ times more — which is why sunlight can warm the planet despite the Sun's distance. Second, a warming surface automatically radiates more power: this is how Earth eventually restores the balance between energy received and energy lost, at a higher temperature, when the greenhouse effect is enhanced.

The evidence for human influence. The enhanced greenhouse effect is not an assumption; it rests on measured quantities:

- **The gas balance has changed, and the change is human in origin.** The carbon dioxide concentration measured at Mauna Loa has risen from $401.01\,\mathrm{ppm}$ (annual mean, 2015) to $427.35\,\mathrm{ppm}$ (annual mean, 2025), on top of the rise from about $280\,\mathrm{ppm}$ before the industrial era — an increase of more than $50\,\%$. The added carbon matches what is released by burning fossil fuels and by clearing land.

  Source: NOAA Global Monitoring Laboratory, *Trends in Atmospheric Carbon Dioxide* (Mauna Loa Observatory annual means), retrieved 2026-08-18.

- **The temperature has changed in the direction the mechanism predicts.** The global mean near-surface temperature in 2024 was $1.55 \pm 0.13\,°\mathrm{C}$ above the 1850–1900 average, the warmest year on record.

  Source: World Meteorological Organization, *State of the Global Climate 2024*, retrieved 2026-08-18.

- **The warming is seen locally as well as globally.** Australia's climate has warmed by about $1.5\,°\mathrm{C}$ since 1910.

  Source: CSIRO and Bureau of Meteorology, *State of the Climate 2024*, retrieved 2026-08-18.

- **The surface materials have changed.** Land clearing, urban growth and the loss of bright snow and ice have reduced the albedo of large regions, so a greater share of the incoming solar radiation is absorbed and transformed into thermal energy (2D).

The physics connecting these measurements is the absorption and re-emission of infrared by greenhouse gases, which is directly measurable in the laboratory. Evaluating sources of such evidence, and communicating a physics-informed response to climate claims in the media, is the work of 10A and 10B, which every Option 2.1 communication draws on.

Method notes. Always convert Celsius to kelvin before using Wien's Law or the Stefan–Boltzmann Law ($T(\mathrm{K}) = T(^\circ\mathrm{C}) + 273$, from 2A); convert $\mu\mathrm{m}$ and nm to metres ($1\,\mu\mathrm{m} = 10^{-6}\,\mathrm{m}$, $1\,\mathrm{nm} = 10^{-9}\,\mathrm{m}$); and when using $P \propto T^4$, take the ratio of the kelvin temperatures *first*, then raise to the fourth power — a ratio of Celsius temperatures is meaningless.

Links to other sections. The spectrum regions are those of 1B; kelvin conversion and energy transfer by radiation are 2A and 2D; Wien's Law and the comparison of radiation curves are 2C. The enhanced greenhouse effect applies the energy-transfer ideas of 2D to the whole planet. The communication skills assessed by the Option task at the end of this section are taught in 10A and 10B.

Worked examples

Example 1 — scaffolded

The mean surface temperature of Earth is about $15\,^\circ\mathrm{C}$. Calculate the peak wavelength of the electromagnetic radiation re-emitted by Earth's surface, and name the region of the electromagnetic spectrum in which it lies.

Working	Comment
$T = 15 + 273 = 288\,\mathrm{K}$.	Wien's Law requires the absolute temperature in kelvin (2A).
$\lambda_{\max} = \dfrac{2.9\times10^{-3}}{T} = \dfrac{2.9\times10^{-3}}{288} = 1.0\times10^{-5}\,\mathrm{m}$.	Rearrange Wien's Law for $\lambda_{\max}$ and substitute.
$1.0\times10^{-5}\,\mathrm{m} = 10\,\mu\mathrm{m}$.	$1\,\mu\mathrm{m} = 10^{-6}\,\mathrm{m}$.
$10\,\mu\mathrm{m}$ lies in the **infrared** region.	Much longer than visible light (400–$700\,\mathrm{nm}$, 1B). This is the radiation the greenhouse gases absorb.

Example 2 — scaffolded

On a hot day, a satellite records a bare dry-soil paddock at $45\,^\circ\mathrm{C}$ and the surrounding vegetated farmland at $25\,^\circ\mathrm{C}$. Use the Stefan–Boltzmann Law to compare the power radiated per unit area by the two surfaces.

Working	Comment
$T_1 = 25 + 273 = 298\,\mathrm{K}$ (vegetation); $T_2 = 45 + 273 = 318\,\mathrm{K}$ (bare soil).	Convert both temperatures to kelvin first.
$\dfrac{P_2}{P_1} = \left(\dfrac{T_2}{T_1}\right)^4 = \left(\dfrac{318}{298}\right)^4 = (1.067)^4 \approx 1.3$.	The Stefan–Boltzmann Law, $P \propto T^4$, as a ratio.
The bare soil radiates about 1.3 times the power per unit area of the vegetation.	A $20\,^\circ\mathrm{C}$ difference already changes the radiated power by about $30\,\%$ — the fourth power acts quickly.

Example 3 — unscaffolded

Compare the radiation emitted by the surface of the Sun ($5800\,\mathrm{K}$) with the radiation re-emitted by the mean surface of Earth ($288\,\mathrm{K}$), referring to the peak wavelength and the total energy emitted across the electromagnetic spectrum. Hence explain why greenhouse gases intercept the outgoing radiation but let most of the incoming solar radiation pass.

The Sun: $\lambda_{\max} = \dfrac{2.9\times10^{-3}}{5800} = 5.0\times10^{-7}\,\mathrm{m} = 500\,\mathrm{nm}$, in the visible region (2C). Earth: $\lambda_{\max} = \dfrac{2.9\times10^{-3}}{288} = 1.0\times10^{-5}\,\mathrm{m} = 10\,\mu\mathrm{m}$, in the infrared. The hotter Sun therefore peaks at a wavelength twenty times shorter than Earth's.

Per unit area, the Stefan–Boltzmann Law gives the ratio of radiated powers:

$$\frac{P_{\text{Sun}}}{P_{\text{Earth}}} = \left(\frac{5800}{288}\right)^4 \approx 1.6 \times 10^5,$$

and the Sun's radiation curve lies above Earth's at every wavelength, so the Sun emits far more total energy across the whole spectrum. The radiation arriving at Earth is therefore short-wave (visible and near-infrared) radiation, while the radiation Earth re-emits is long-wave thermal infrared. Greenhouse gases absorb strongly at the long infrared wavelengths Earth emits and only weakly at the short wavelengths the Sun sends, so most of the incoming solar radiation passes through the atmosphere to the surface, while much of the outgoing infrared is absorbed and re-emitted, part of it back toward the surface.

∴ the Sun peaks at $500\,\text{nm}$ (visible) and radiates about 1.6×10^5 times more power per unit area than Earth's surface; Earth re-emits at about $10\,\mu\text{m}$ (infrared), and it is this long-wave radiation that the greenhouse gases absorb and re-emit.

Example 4 — unscaffolded

Suppose Earth's surface warms from $288\,\text{K}$ to $291\,\text{K}$. Calculate the factor by which the power it radiates changes, and explain the role of this change in the enhanced greenhouse effect.

By the Stefan–Boltzmann Law,

$$\frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^4 = \left(\frac{291}{288}\right)^4 = (1.0104)^4 \approx 1.04,$$

so a $3\,\text{K}$ warming increases the radiated power by about $4\,\%$.

This increase is the restoring balance of the climate system. The surface is in balance when the energy it receives (solar radiation plus the infrared returned by the greenhouse gases) equals the energy it radiates. When human activity adds greenhouse gases, the atmosphere returns more infrared to the surface, so at the old temperature the surface receives more energy than it radiates and it warms. As it warms, $P \propto T^4$ makes it radiate more, until emission once again balances absorption — now at a higher temperature. That new, higher balance temperature **is** the global warming produced by the enhanced greenhouse effect.

∴ the radiated power increases by a factor of about 1.04; the warming continues until the extra radiation from the hotter surface balances the extra infrared returned by the added greenhouse gases.

Practice questions

Question 1 *(scaffolded)* The mean surface temperature of Earth is about $15\,°\text{C}$. (a) Convert $15\,°\text{C}$ to kelvin. (b) Write down Wien's Law, including the value and units of the constant. (c) Calculate the peak wavelength of the radiation re-emitted by Earth's surface, and state the region of the electromagnetic spectrum in which it lies.

Question 2 *(scaffolded)* A thermal camera on a satellite measures radiation from the ocean surface peaking at a wavelength of $10\,\mu\text{m}$. (a) Convert $10\,\mu\text{m}$ to metres. (b) Rearrange Wien's Law to make T the subject, and calculate the temperature of the ocean surface in kelvin. (c) The surface of the Sun is at about $5800\,\text{K}$ and peaks at $500\,\text{nm}$. State which body is hotter, and check that your answer is consistent with Wien's Law.

Question 3 *(scaffolded)* The Stefan–Boltzmann Law states that the power radiated by a body depends on its temperature as $P \propto T^4$. (a) A body's absolute temperature is doubled. By what factor does the power it radiates change? (b) A body's absolute temperature is tripled. By what factor does the power it radiates change? (c) The power radiated by a body increases by a factor of 16. By what factor has its absolute temperature changed?

Question 4 *(scaffolded)* The study design names three greenhouse gases in the atmosphere. (a) List the three greenhouse gases named in the study design. (b) Describe what these gases do to the infrared radiation emitted by Earth's surface. (c) State the effect this has on the mean temperature of the surface.

Question 5 *(scaffolded)* The table gives the annual mean carbon dioxide concentration measured at Mauna Loa.

Year	2015	2018	2021	2025
CO_2 (ppm)	401.01	408.72	416.41	427.35

(a) Calculate the increase in the CO_2 concentration between 2015 and 2025.
(b) Estimate the average rate of increase, in ppm per year, over this decade.
(c) Describe the trend, and explain what it means for the enhanced greenhouse effect.

Question 6 *(scaffolded)* The following steps describe the transformation of radiation as it passes through the atmosphere, is absorbed and re-emitted by Earth, but they are out of order:

A. Greenhouse gases absorb some of this infrared radiation and re-emit it in all directions, part of it back toward the surface.

B. Solar radiation passes through the atmosphere and is absorbed by the surface, transforming into thermal energy.

C. The warmed surface re-emits energy as long-wavelength infrared radiation.

D. The surface warms above the temperature it would have without the atmosphere.

(a) Write the steps in the correct order.
(b) Name the overall effect described by the complete sequence.

Question 7 Calculate the peak wavelength of the radiation emitted by the surface of the Sun ($5800\,\mathrm{K}$) and the peak wavelength of the radiation re-emitted by the mean surface of Earth ($288\,\mathrm{K}$). State the region of the spectrum for each, and hence explain why the atmosphere is largely transparent to incoming solar radiation yet absorbs much of the radiation leaving Earth.

Question 8 A cleared, dark urban surface reaches $47\,°\mathrm{C}$ on a summer day while a nearby vegetated park is at $27\,°\mathrm{C}$. Use the Stefan–Boltzmann Law to calculate the ratio of the power radiated per unit area by the urban surface to that radiated by the park.

Question 9 Explain the natural greenhouse effect, and state, with the temperatures involved, why Earth's mean surface temperature is about $33\,°\mathrm{C}$ warmer than it would be without an atmosphere.

Question 10 Before the industrial era the carbon dioxide concentration was about $280\,\mathrm{ppm}$; the 2025 annual mean at Mauna Loa is $427.35\,\mathrm{ppm}$. (a) Calculate the percentage increase in the CO_2 concentration since the pre-industrial era, to two significant figures. (b) Explain what is meant by the *enhanced* greenhouse effect, and how this increase produces it.

Question 11 Explain, in terms of the absorption and re-emission of infrared radiation, why adding carbon dioxide to the atmosphere leads to global warming.

Question 12 Analyse the following evidence and evaluate the extent to which it supports the claim that human activity is creating an enhanced greenhouse effect:

- the CO_2 concentration has risen from about $280\,\mathrm{ppm}$ to $427.35\,\mathrm{ppm}$, with the added carbon matching fossil-fuel burning and land clearing;
- the global mean near-surface temperature in 2024 was $1.55 \pm 0.13\,°\mathrm{C}$ above the 1850–1900 average;
- Australia's climate has warmed by about $1.5\,°\mathrm{C}$ since 1910;
- land clearing and urban growth have darkened large areas of Earth's surface.

Question 13 Methane makes up far less of the atmosphere than carbon dioxide does. Explain why methane is nevertheless a greenhouse gas, and why even a small concentration matters.

Question 14 Large areas of forest have been cleared for darker farmland, and bright snow and ice are melting to reveal darker ground and ocean beneath. With reference to albedo and energy transfer, explain how these changes to the materials that comprise the surface of Earth contribute to warming.

Question 15 A student claims: “The greenhouse effect is harmful, so the best outcome would be to remove it completely.” Evaluate this claim using the physics of this section.

Question 16 A desert surface is at $40\,°\text{C}$ late in the afternoon and falls to $10\,°\text{C}$ by dawn. (a) Calculate the ratio of the power radiated per unit area at dawn to the power radiated in the afternoon. (b) Deserts cool quickly on clear nights because the dry air holds little water vapour. Explain this observation using the greenhouse mechanism.

Question 17 Using the Stefan–Boltzmann Law, calculate the ratio of the power radiated per unit area by the surface of the Sun ($5800\,\text{K}$) to that radiated by the mean surface of Earth ($288\,\text{K}$). Comment on what this ratio, together with the peak wavelengths of the two bodies, tells you about the radiation arriving at Earth compared with the radiation leaving it.

Question 18 A commentator writes: “The climate has changed naturally in the past, so today’s warming cannot be caused by human activity.” Evaluate this argument using the physics of the greenhouse effect and the evidence in Question 12.

Question 19 Explain why the ground cools much more on a clear, dry night than on a cloudy, humid night, referring to the absorption and re-emission of infrared radiation by water vapour and clouds.

Answers

Question 1 (a) $288\,\text{K}$; (b) $\lambda_{max} T = 2.9\times10^{-3}$ m K; (c) 1.0×10^{-5} m ($10\,\mu$m), infrared. **Question 2** (a) 1.0×10^{-5} m ; (b) $290\,\text{K}$; (c) the Sun is hotter; consistent — the hotter body peaks at the shorter wavelength ($500\,\text{nm} < 10\,\mu\text{m}$). **Question 3** (a) 16; (b) 81; (c) 2. **Question 4** (a) methane, water (as water vapour), carbon dioxide; (b) they absorb the outgoing infrared and re-emit it in all directions, part back toward the surface; (c) the surface is kept warmer than it would be otherwise (the greenhouse effect). **Question 5** (a) 26.34 ppm; (b) about 2.6 ppm per year; (c) steady rise — more greenhouse gas means more outgoing infrared returned to the surface, enhancing the greenhouse effect. **Question 6** (a) B, C, A, D; (b) the (natural) greenhouse effect. **Question 7** Sun 5.0×10^{-7} m (500 nm, visible); Earth 1.0×10^{-5} m ($10\,\mu$m, infrared); greenhouse gases absorb the long outgoing wavelengths, not the short incoming ones. **Question 8** about 1.3. **Question 9** see solutions. **Question 10** (a) about 53 %; (b) see solutions. **Question 11** see solutions. **Question 12** see solutions. **Question 13** see solutions. **Question 14** see solutions. **Question 15** see solutions. **Question 16** (a) about 0.67; (b) see solutions. **Question 17** about 1.6×10^{5}; incoming radiation is short-wave and intense per unit area at the source, outgoing is long-wave infrared. **Question 18** see solutions. **Question 19** see solutions.

Fully-worked solutions

Question 1 (a) $T = 15 + 273 = 288\,\text{K}$. (b) Wien's Law is $\lambda_{max} T = \text{constant} = 2.9\times10^{-3}$ m K, where λ_{max} is the peak wavelength in metres and T the absolute temperature in kelvin. (c) $\lambda_{max} = \frac{2.9\times10^{-3}}{288} = 1.0\times10^{-5}\,\text{m} = 10\,\mu\text{m}$, in the **infrared** region.

Question 2 (a) $10\,\mu\text{m} = 10\times10^{-6}\,\text{m} = 1.0\times10^{-5}\,\text{m}$. (b) $T = \frac{2.9\times10^{-3}}{\lambda_{max}} = \frac{2.9\times10^{-3}}{1.0\times10^{-5}} = 290\,\text{K}$. (c) The Sun (5800 K) is hotter than the ocean surface (290 K). Check: Wien's Law says the hotter body has the shorter peak wavelength; 500 nm is far shorter than $10\,\mu\text{m} = 10\,000\,\text{nm}$, so the answer is consistent.

Question 3 (a) $(2T/T)^4 = 2^4 = 16$. (b) $3^4 = 81$. (c) $16 = 2^4$, so the absolute temperature has doubled (factor 2).

Question 4 (a) The three greenhouse gases named in the study design are methane, water (as water vapour) and carbon dioxide. (b) These gases absorb the infrared radiation emitted by Earth's surface and re-emit it in all directions; a large share of the re-emitted radiation travels back downward and is absorbed by the surface again. (c) The surface therefore receives extra energy and settles at a higher mean temperature than it would without the atmosphere — the greenhouse effect.

Question 5 (a) $427.35 - 401.01 = 26.34$ ppm. (b) $26.34/10 \approx 2.6$ ppm per year. (c) The concentration rises steadily, at an increasing rate. Each added part per million of CO_2 adds to the absorption and re-emission of outgoing infrared, so the rising trend means the greenhouse effect is being enhanced — more infrared is returned to the surface than before the industrial era.

Question 6 (a) B (solar radiation absorbed by the surface), C (surface re-emits infrared), A (greenhouse gases absorb and re-emit, part back downward), D (surface warms above the no-atmosphere temperature). (b) The sequence describes the **greenhouse effect**.

Question 7 Sun: $\lambda_{max} = \frac{2.9\times10^{-3}}{5800} = 5.0\times10^{-7}\,\text{m} = 500\,\text{nm}$, in the visible region. Earth: $\lambda_{max} = \frac{2.9\times10^{-3}}{288} = 1.0\times10^{-5}\,\text{m} = 10\,\mu\text{m}$, in the infrared region. The incoming solar radiation is therefore concentrated at short wavelengths at which the greenhouse gases absorb only weakly, so most of it passes through to the surface; the outgoing radiation is concentrated at the long infrared wavelengths the greenhouse gases absorb strongly, so much of it is intercepted and re-emitted, part back toward the surface.

Question 8 $T_{park} = 27 + 273 = 300\,\text{K}$; $T_{urban} = 47 + 273 = 320\,\text{K}$.

$$\frac{P_{\text{urban}}}{P_{\text{park}}} = \left(\frac{320}{300}\right)^4 = (1.067)^4 \approx 1.3.$$

The urban surface radiates about 1.3 times the power per unit area of the park.

Question 9 Model answer (4 marks): Greenhouse gases in the atmosphere — mainly water vapour, carbon dioxide and methane — absorb the infrared radiation emitted by the warm surface and re-emit it in all directions, part of it back toward the surface (1 mark). The surface therefore receives energy from the atmosphere as well as from the Sun (1 mark). Without this effect the mean surface temperature would be about $255\,\text{K}$ (about $-18\,°\text{C}$); with it, the observed mean is about $288\,\text{K}$ (15 °C) (1 mark). The difference, about $33\,°\text{C}$, is the natural greenhouse effect, and it keeps Earth above freezing and habitable (1 mark).

Question 10 (a) Increase $= 427.35 - 280 = 147.35\,\text{ppm}$; percentage increase $= \frac{147.35}{280} \times 100\,\% \approx 53\,\%$. (b) Model answer for the explanation (2 marks): The *enhanced* greenhouse effect is the additional warming caused by human-added greenhouse gases, on top of the natural effect (1 mark). With about $53\,\%$ more CO_2, the atmosphere absorbs and re-emits more of the outgoing infrared and returns more of it to the surface, so the surface must warm until its greater radiation (Stefan–Boltzmann Law) restores the balance (1 mark).

Question 11 Model answer (3 marks): Carbon dioxide molecules absorb the infrared radiation emitted by the surface and re-emit it in all directions, so part of the outgoing energy is sent back to the surface (1 mark). Adding CO_2 increases this absorption and re-emission, so the surface receives more energy than it did before while the incoming solar radiation is unchanged (1 mark). The surface therefore warms — and keeps warming until, by $P \propto T^4$, it radiates enough extra power to balance the extra returned energy. That rise in mean surface temperature is global warming (1 mark).

Question 12 Model answer (4 marks): The evidence strongly supports the claim. The gas balance has changed in the direction of human activity: the CO_2 rise of more than $50\,\%$ matches the carbon released by fossil-fuel burning and land clearing, and methane has more than doubled (1 mark). The temperature has changed in the direction the mechanism predicts: the warmest year on record, $1.55\,°\text{C}$ above 1850–1900 globally and about $1.5\,°\text{C}$ of Australian warming since 1910, is consistent with an enhanced greenhouse effect (1 mark). The surface materials have changed too: darker cleared and urban surfaces lower the albedo, so more incoming solar energy is absorbed and transformed into thermal energy (1 mark). A limitation is that a rising curve beside a rising curve is a correlation; what turns it into evidence for *causation* is the independently verified mechanism — infrared absorption by greenhouse gases is measured directly in the laboratory (1 mark).

Question 13 Model answer (3 marks): A methane molecule acts on infrared radiation in the same way as carbon dioxide and water vapour: it absorbs the outgoing infrared and re-emits it in all directions, part back toward the surface, so rising methane concentrations add to the greenhouse effect and to global warming (1 mark). Its concentration is much smaller than that of CO_2 (1 mark), but molecule for molecule methane absorbs infrared much more strongly than carbon dioxide does, so even a trace concentration has a measurable effect (1 mark).

Question 14 Model answer (4 marks): Albedo is the fraction of the incoming solar radiation a surface reflects (1 mark). Forest, and especially snow and ice, reflect more than the darker farmland, ground and ocean that replace them, so after clearing and melting the surface absorbs a larger share of the incoming solar radiation (1 mark). The extra absorbed radiation is transformed into thermal energy of the surface and the air above it (1 mark). These human changes to the surface materials therefore add warming alongside the changes in the balance of gases — a second pathway by which human activity enhances the warming (1 mark).

Question 15 Model answer (3 marks): The claim is incorrect (1 mark). The natural greenhouse effect keeps the mean surface about $33\,°\text{C}$ warmer than it would otherwise be — without it the surface would average about $-18\,°\text{C}$ (about $255\,\text{K}$), the oceans would freeze, and Earth would not support life as it does (1 mark). The real concern is the *enhanced* greenhouse effect, the extra warming from human-added gases; removing the natural effect entirely would be a catastrophe, not an improvement (1 mark).

Question 16 (a) $T_{\text{afternoon}} = 40 + 273 = 313\,\text{K}$; $T_{\text{dawn}} = 10 + 273 = 283\,\text{K}$.

$$\frac{P_{\text{dawn}}}{P_{\text{afternoon}}} = \left(\frac{283}{313}\right)^4 = (0.904)^4 \approx 0.67.$$

At dawn the surface radiates only about two-thirds of the power it radiated in the afternoon. (b) Model answer for the explanation (2 marks): Through the night the surface loses energy by radiating infrared — part (a) shows a surface near $300\,\text{K}$ radiates strongly — with no sunlight replacing it (1 mark). Water vapour is a greenhouse gas: humid or cloudy air absorbs much of that outgoing infrared and re-emits part of it back to the surface, slowing the cooling; dry desert air returns little, so the surface loses energy quickly and cools rapidly (1 mark).

Question 17 $\frac{P_{\text{Sun}}}{P_{\text{Earth}}} = \left(\frac{5800}{288}\right)^4 = (20.1)^4 \approx 1.6 \times 10^5$. Per unit area, the Sun's surface radiates about $160\,000$ times more power than Earth's surface. Combined with the peak wavelengths ($500\,\text{nm}$ in, $10\,\mu\text{m}$ out), this tells you that the radiation arriving at Earth is intense, short-wave radiation able to pass through the atmosphere, while the radiation leaving Earth is far weaker per unit area and concentrated in the long-wave infrared that the greenhouse gases intercept. Earth stays in balance because its whole surface radiates continuously, and because the incoming beam is spread over the planet's cross-section.

Question 18 Model answer (4 marks): The argument rests on a true fact — the climate has changed naturally in the past (1 mark). But past natural change is evidence *for* the greenhouse physics, not against it: whenever the energy balance changed in the past (through volcanic activity, solar output or natural changes in greenhouse gases), the climate responded exactly as the energy-balance argument predicts (1 mark). The present change is different in cause and in rate: the CO_2 rise to $427\,\text{ppm}$ tracks human emissions, and its rate is far faster than the natural changes preserved in ice cores (1 mark). So the argument fails — natural change in the past does not remove a human cause now; it confirms that adding greenhouse gases warms the climate (1 mark).

Question 19 Model answer (3 marks): At night the surface loses energy by radiating infrared, with no incoming solar radiation to replace it (1 mark). Water vapour and cloud droplets are greenhouse absorbers: on a cloudy, humid night they absorb the outgoing infrared and re-emit part of it back to the surface, returning energy and slowing the cooling (1 mark). On a clear, dry night little of the outgoing infrared is returned, so the surface keeps losing energy and the temperature falls much further (1 mark).

Option task — a physics-informed media response (30 marks)

House Option task (house convention — school-based assessment; Units 1 & 2 carry no VCAA examination, and levels of achievement are a matter for school decision). Outcome 2 task type: a media analysis/response and a physics-referenced response to an issue. The rubric is keyed to the Communicating physics dot points `U2.2.CP.1` `–.5` (taught in 10A and 10B).

Stimulus — *constructed for this task; not a quotation.* A social-media post reads:

> "CO_2 is only 0.04% of the atmosphere — a trace gas cannot run the climate. The greenhouse effect is completely natural, so any warming we measure must be natural too. Physics says relax."

Answer all parts. Your response will be assessed against the rubric below.

(a) Evaluate the validity of the social-media post as a source of information about climate, and identify the two physics claims in the post that are testable. (4 marks)

(b) Using a mean surface temperature of $15\,°\text{C}$, calculate the peak wavelength of the radiation re-emitted by Earth and name the region of the spectrum. Hence, using appropriate terminology, explain whether CO_2 intercepts the incoming solar radiation or the outgoing radiation, and why the size of the $0.04\,\%$ figure does not settle the question by itself. (6 marks)

(c) The post implies the greenhouse effect is unchanging. Using the Mauna Loa record (280 ppm pre-industrial; 401.01 ppm in 2015; 427.35 ppm in 2025), the Stefan–Boltzmann Law and one change to the materials that comprise Earth's surface, explain the enhanced greenhouse effect, and discuss one limitation of modelling Earth as a simple radiating body in this argument. (8 marks)

(d) Discuss two sociocultural, economic, legal or political factors that influence how a community responds to the enhanced greenhouse effect. (6 marks)

(e) Apply your physics understanding to justify a stance on the post's conclusion ("Physics says relax"). (6 marks)

Rubric (keyed to the Communicating physics dot points).

Dot point	What a high-quality response does
`U2.2.CP.1` evaluate validity of sources	Names the post as opinion, not data; identifies what a valid source would be (measured records such as the Mauna Loa CO_2 series and the WMO temperature assessment) and tests the post against them (part a).
`U2.2.CP.2` physics concepts, terminology, representations	Uses greenhouse gas, absorption, re-emission, infrared, peak wavelength and albedo correctly; the Wien's Law calculation is shown with kelvin conversion and units (part b).
`U2.2.CP.3` data representations, models and limitations	Reads the CO_2 trend from the data; applies $P \propto T^4$ to the balance argument; states a genuine limitation of the simple radiating-body model (e.g. it leaves out albedo changes, clouds, convection and the ocean's storage of thermal energy) (part c).
`U2.2.CP.4` sociocultural, economic, legal and political factors	Discusses two distinct factors (e.g. the cost and availability of alternatives to fossil fuels; employment in affected industries; government policy and international agreements; public trust in institutions) without letting them replace the physics (part d).
`U2.2.CP.5` justify a stance with physics	Takes a clear stance on the conclusion and justifies it from the mechanism and the measured evidence, acknowledging the natural greenhouse effect while rejecting "relax" on the basis of the enhanced effect (part e).

Chapter 10 Options: communicating physics, climate, nuclear and medical physics — 10D Option 2.2: How do fusion and fission compare as viable nuclear energy power sources?

Theory

This subtopic is Option 2.2 of Unit 2, Area of Study 2. The study design introduces the option like this:

> In this option students focus on communicating physics understanding in the context of fission and fusion reactions. Fission and fusion are nuclear reactions that produce relatively large quantities of energy from comparatively small quantities of fuel. In preparing their communication related to a selected contemporary societal issue or application, students explore fission and fusion reactions as power sources.
>
> *VCE Physics Study Design, Unit 2, Area of Study 2*

You already hold the general physics. Chapter 3 described the nucleus, its radiation and its decays; Chapter 4 explained where nuclear energy comes from — the conversion of mass (4A) — how a fission chain reaction is controlled (4B), how fission and fusion compare in broad terms (4C), and whether nuclear energy is viable *for Australia* (4D). This option goes deeper than Chapter 4 on the *specific reactions* the study design names. It owns five key knowledge dot points:

- explain nuclear fusion reactions of proton-proton and deuterium-tritium with reference to:
  - reactants, products and energy production
  - availability of reactants
  - energy production compared with mass of fuel
- explain nuclear fission reactions of ^{235}U and ^{239}Pu with reference to:
  - fission initiation by slow and fast neutrons respectively
  - products of fission including typical unstable fission fragments and energy
  - radiation produced by unstable fission fragments
- describe neutron absorption in ^{238}U, including formation of ^{239}Pu
- describe the energy transfers and transformations in the systems that convert nuclear energy into thermal energy for subsequent power generation
- explain the risks and benefits for society of using nuclear energy as a power source

The subtopic closes with the assessed Option task for this option, which is marked against the *Communicating physics* dot points taught in 10A and 10B.

Fusion reaction 1 — the proton–proton chain. The Sun and other stars of similar size are powered by the fusion of ordinary hydrogen nuclei. Each hydrogen nucleus, $^{1}_{1}$H, is a single proton. The reaction runs through a short sequence of steps called the **proton–proton chain**:

1. Two protons fuse to form a deuterium nucleus, $^{2}_{1}$H, emitting a positron. (The positron is the β^{+} particle of 3B. It immediately meets an electron, and the two annihilate — both disappear, and their mass becomes energy, as described in 4A.) Two nearly massless particles called neutrinos are also produced in the chain; they carry a small share of the energy straight out of the Sun, and in this book they are omitted from the equations.
2. The deuterium nucleus fuses with another proton to form helium-3, $^{3}_{2}$He, releasing a gamma ray.
3. Two helium-3 nuclei fuse to form helium-4, $^{4}_{2}$He, releasing two protons, which are free to start the chain again.

Adding the steps together, the net reaction of the proton–proton chain is

$$4\ ^{1}_{1}\mathrm{H} \rightarrow\ ^{4}_{2}\mathrm{He} + 2\ ^{0}_{+1}\mathrm{e} + \text{energy}\,.$$

Check the accounting, as in 3B: the nucleon numbers balance ($4 \times 1 = 4 + 0$) and the charges balance ($4 \times 1 = 2 + 2 \times 1$). Each time the chain runs once, four protons are consumed, one helium-4 nucleus is produced, and about $26.7\ \mathrm{MeV}$

(4.3×10^{-12} J) is released. That energy comes from the conversion of mass (4A): the helium-4 nucleus and the two positrons together have slightly less mass than the four protons that made them.

Availability of the reactants. Hydrogen is by far the most abundant element in the Universe, and stars are mostly hydrogen, so the proton–proton chain has an enormous fuel supply. The Sun has shone by this reaction for about 4.6 billion years and has enough hydrogen to continue for about another 5 billion.

Source: NASA Science, Sun facts, retrieved 2026-08-18.

In the Sun's core, about 6×10^8 tonnes of hydrogen are fused every second, and about 4×10^6 tonnes of mass are converted into energy every second (Worked Example 2).

Source: NASA Science, Sun facts, retrieved 2026-08-18.

Yet the proton–proton chain is useless as a power source on Earth. Its first step — two bare protons fusing — is governed by the weak nuclear force (3A) and is extraordinarily unlikely; even in the Sun's dense, hot core, any given proton waits billions of years on average before it succeeds. The Sun can afford to wait, because it is enormous. A machine on Earth, with a fuel supply grams to kilograms in size, could never get useful power from this reaction. Earth-based fusion must use heavier hydrogen isotopes that fuse far more readily — deuterium and tritium.

Fusion reaction 2 — deuterium–tritium. In 4C you met the reaction pursued by almost all current fusion experiments: the fusion of deuterium, ${}^{2}_{1}\text{H}$, and tritium, ${}^{3}_{1}\text{H}$, the two heavier isotopes of hydrogen. The reaction is

$${}^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + {}^{1}_{0}\text{n} + \text{energy}.$$

The total energy released is $17.6\,\text{MeV}$ per reaction, which is 2.8×10^{-12} J (the figure used in 4C). The energy is shared unevenly between the two products: the helium nucleus carries $3.5\,\text{MeV}$ and the neutron carries $14.1\,\text{MeV}$ — about $80\,\%$ of the total. Both products matter for a future power station. The helium is stable and non-radioactive; in a machine, its kinetic energy becomes thermal energy of the surrounding material. The fast neutron escapes the plasma and is absorbed in a surrounding **blanket**, where its kinetic energy also becomes thermal energy — and where it can be used to manufacture fresh tritium, as described below.

Availability of the reactants. Deuterium occurs naturally in seawater: about one hydrogen atom in every 6500 is a deuterium atom. The oceans hold an enormous supply — far more than humanity could use in any foreseeable future.

Source: World Nuclear Association, Nuclear Fusion Power, retrieved 2026-08-18.

Tritium is different. It is radioactive — it decays by β^- emission with a half-life of 12.3 years (3C) — so almost none survives from the Earth's formation, and it must be manufactured. In a future fusion station it would be made inside the machine itself, in the blanket, by absorbing the neutrons that the fusion reactions release into lithium-6:

$${}^{1}_{0}\text{n} + {}^{6}_{3}\text{Li} \rightarrow {}^{3}_{1}\text{H} + {}^{4}_{2}\text{He} + \text{energy}.$$

Lithium is a plentiful element in the Earth's crust and is also present in seawater. One neutron from each deuterium–tritium fusion can, in principle, breed one tritium nucleus to replace the one that was consumed, so the station makes its own tritium fuel as it runs. ITER, the international experiment described in 4C, is designed to test blanket modules that do exactly this.

Source: World Nuclear Association, Nuclear Fusion Power, retrieved 2026-08-18. Source: ITER Organization, https://www.iter.org, retrieved 2026-08-18.

Energy production compared with mass of fuel. Both fusion reactions convert a measurable fraction of their fuel's mass into energy (4A), and that fraction is larger than for fission. The comparison is worked out in Questions 6 and 17; the results are:

Reaction	Energy released	Fraction of fuel mass converted
proton–proton chain (four protons)	about $26.7\,\text{MeV}$	about $0.7\,\%$
deuterium–tritium	$17.6\,\text{MeV}$	about $0.4\,\%$
fission of ${}^{235}\text{U}$	about $200\,\text{MeV}$	about $0.1\,\%$ (4D)

Per kilogram of fuel, the lighter the nuclei, the more reactions there are in a kilogram, so the order is the same: fusing $1\,\mathrm{kg}$ of hydrogen by the proton–proton chain would release about 6.4×10^{14} J; $1\,\mathrm{kg}$ of deuterium–tritium fuel releases about 3.4×10^{14} J (Worked Example 1); $1\,\mathrm{kg}$ of ^{235}U releases about 8.2×10^{13} J (4D). All three are millions of times larger than the roughly 10^{7} J released by burning $1\,\mathrm{kg}$ of a chemical fuel. Fusion fuel is the most energy-dense fuel there is — but only if the reaction can be made to run.

Fission reaction 1 — uranium-235 with slow neutrons. In 4B you saw the reaction that runs today's reactors: a ^{235}U nucleus absorbs a slow neutron and splits. One of the many possible fission events is

$$^{1}_{0}\mathrm{n} + {}^{235}_{92}\mathrm{U} \rightarrow {}^{140}_{54}\mathrm{Xe} + {}^{94}_{38}\mathrm{Sr} + 2\,{}^{1}_{0}\mathrm{n} + \text{energy}$$

(check the accounting: nucleons $1+235=140+94+2$; charges $0+92=54+38$). The fragments are different in almost every fission — hundreds of pairs are possible — but they always add up, together with the released neutrons, to the original 236 nucleons, and each fission releases about $200\,\mathrm{MeV}$ (3.2×10^{-11} J), mostly as kinetic energy of the two fragments.

The initiating neutron must be **slow**. A slow neutron spends longer in the neighbourhood of a ^{235}U nucleus as it passes, so it is far more likely to be absorbed than a fast one; and absorption by ^{235}U is what starts the fission. This is why today's reactors contain a **moderator** — a material of light nuclei that slows the fast fission neutrons by repeated collisions — as explained in 4B.

Fission reaction 2 — plutonium-239 with fast neutrons. ^{239}Pu is the second fission fuel named by the study design. It does not occur naturally in useful amounts; it is made inside reactors from ^{238}U, by the absorption process described below. A reactor that runs on ^{239}Pu is usually a **fast reactor**: it has no moderator at all, so its neutrons stay fast, and the chain reaction is carried by fast neutrons initiating fission of ^{239}Pu. One possible event is

$$^{1}_{0}\mathrm{n} + {}^{239}_{94}\mathrm{Pu} \rightarrow {}^{144}_{58}\mathrm{Ce} + {}^{92}_{36}\mathrm{Sr} + 4\,{}^{1}_{0}\mathrm{n} + \text{energy}$$

(nucleons $1+239=144+92+4$; charges $0+94=58+36$). Like ^{235}U fission, each event releases about $200\,\mathrm{MeV}$ and two or more neutrons, so it too can sustain a chain reaction (4B).

Typical unstable fission fragments and their radiation. Fission fragments are unstable, and the reason takes us back to 3A. A heavy nucleus like uranium needs proportionally more neutrons than protons to be stable — the extra neutrons add strong-nuclear-force attraction without adding electrostatic repulsion. When such a nucleus splits, the two fragments inherit that neutron-richness: each has too many neutrons for its new, smaller size. Neutron-rich nuclei move toward stability by converting neutrons into protons, which is β^{-} decay (3B): the fragment emits an electron, and often a gamma ray follows as the daughter nucleus settles into a lower energy state.

Three well-known fragments illustrate the pattern:

Fragment	Half-life	Radiation emitted
iodine-131	8.0 days	β^{-} and γ
strontium-90	28.8 years	β^{-}
caesium-137	30 years	β^{-} and γ

This decay of the fragments is why spent fuel is radioactive and hot. The fragments keep decaying — and releasing energy — long after the chain reaction itself has stopped. In a shut-down reactor this **decay heat** is small compared with full power, but it is large enough to melt the fuel if cooling is lost: that is what happened at Fukushima Daiichi, as described below.

Neutron absorption in uranium-238: making plutonium-239. Natural uranium is $99.3\,\%$ ^{238}U and only $0.7\,\%$ ^{235}U (4D). ^{238}U is not fissile — a slow neutron absorbed by it usually does not cause fission. In 4B this absorption appeared as one of the ways neutrons are lost. It is also a way of making new fuel, because the nucleus that forms does not stay as it is. When ^{238}U absorbs a neutron,

$$^{1}_{0}\mathrm{n} + {}^{238}_{92}\mathrm{U} \rightarrow {}^{239}_{92}\mathrm{U} + \gamma,$$

and the uranium-239 then decays, quickly, by β^- emission ($t_{1/2} \approx 23$ minutes):

$^{239}_{92}U \rightarrow ^{239}_{93}Np + ^{0}_{-1}e$,

forming neptunium-239, which decays in turn by β^- emission ($t_{1/2} \approx 2.4$ days):

$^{239}_{93}Np \rightarrow ^{239}_{94}Pu + ^{0}_{-1}e$,

forming plutonium-239. ^{239}Pu is fissile: it can carry a chain reaction, as described above. If left undisturbed it decays very slowly, by α emission, with a half-life of about $24\,100$ years (3B, 3C).

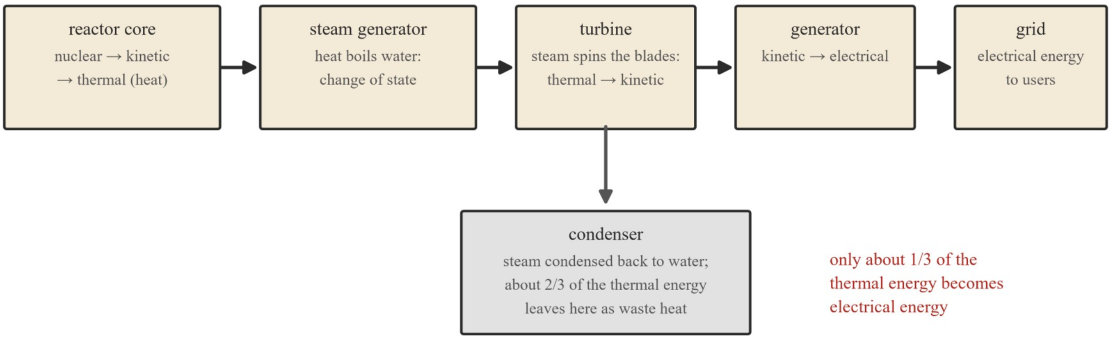
Two consequences follow. First, any reactor fuel that contains ^{238}U — which is most of it — gradually breeds ^{239}Pu while it operates, and some of the energy a reactor produces late in its fuel's life comes from fission of plutonium it made itself. Second, because ^{238}U is $99.3\,\%$ of natural uranium, a technology that could turn ^{238}U into fissile ^{239}Pu — a **breeder** reactor — would extract many times more energy from the same mined uranium. There is a third consequence, which is not about energy: ^{239}Pu is one of the materials from which nuclear weapons can be made, so separated plutonium and spent fuel are counted, guarded and inspected under international **safeguards** — agreements, administered by the International Atomic Energy Agency, under which states verify that nuclear material is not diverted to weapons.

Source: International Atomic Energy Agency, IAEA Safeguards, retrieved 2026-08-18.

From the nucleus to the grid: energy transfers and transformations. Both fission and fusion release their energy inside nuclei; society wants electrical energy. The systems in between perform a chain of transfers and transformations. For a fission station, with each stage's device:

1. **Nuclear → kinetic.** Each fission releases about $200\,\text{MeV}$, appearing mostly as kinetic energy of the two fragments, with the rest as kinetic energy of the neutrons and as gamma radiation. This happens in the fuel, inside the **reactor core**.
2. **Kinetic → thermal.** The fragments travel only a microscopic distance before colliding with the atoms around them. In each collision some kinetic energy is passed on, so the fuel and the core materials heat up: their thermal energy — the kinetic and potential energy of their atoms (2A) — rises. The neutrons and gamma rays are absorbed further out, depositing their energy too.
3. **Thermal energy is transferred to a coolant.** A fluid (for most reactors, water) is pumped through the core, and energy is transferred from the hot core to the cooler fluid by conduction and convection (2A). The coolant carries the energy out of the core to a **steam generator**, where it boils a separate supply of water.
4. **Change of state.** The water becomes high-pressure steam, storing the energy as thermal energy; boiling is a change of state, so the energy involved is a latent heat (2B).
5. **Thermal → kinetic.** The steam expands through a **turbine**, spinning its blades: thermal energy of the steam is transformed into kinetic energy of the turbine.
6. **Kinetic → electrical.** The turbine shaft drives a **generator**, which transforms the kinetic energy into electrical energy, delivered to the grid.
7. **The waste heat leaves.** The spent steam is condensed back to water in a **condenser**, a change of state that releases thermal energy to a cooling system — cooling towers, a river, or the sea — and the water returns to be boiled again.

a nuclear power station: the same energy chain as a coal station,
with the reactor core in place of the boiler



Only about one third of the thermal energy becomes electrical energy; the other two thirds is the waste heat of step 7 (the figure used in 4D). This efficiency limit applies to every thermal power station — nuclear, coal or gas — because all of them work by heating a fluid and spinning a turbine. The *back half* of a nuclear station (steam, turbine, generator, condenser) is the same as a coal-fired station's; the difference is only what makes the heat.

A future **fusion** station would use the same back half. In a deuterium–tritium machine, the $14.1\,\mathrm{MeV}$ neutrons are absorbed in the blanket and the $3.5\,\mathrm{MeV}$ helium nuclei in the plasma-facing walls, and both deposits appear as thermal energy of the blanket and walls. A coolant would carry that thermal energy to a steam generator, and from there the chain of transfers is identical. No fusion machine has yet reached this stage — no fusion machine has yet generated electricity at all (4C) — but the energy transfers of the back half are well-understood engineering, because every thermal station on Earth already performs them.

Risks and benefits for society. The option's title asks how fusion and fission compare as *viable* power sources. *Viable* is a contested term, and 4D handled it as one: it defined a frame — able to supply a significant share of the electricity, at an acceptable cost, within a reasonable time, with safety and environmental effects no worse than the alternatives — and every question in 4D is answerable on that frame. The same discipline applies here: state what you mean, present each case at its strongest, and test both cases with the same standard of evidence. Marking rewards the quality of the reasoning, not the conclusion reached.

Benefits of fission for society.

- **Enormous energy density.** Complete fission of $1\,\mathrm{kg}$ of ^{235}U releases about $8.2 \times 10^{13}\,\mathrm{J}$ — the energy of millions of kilograms of coal (4D). A station needs only tonnes of fuel per year, delivered by a handful of trucks.
- **Low life-cycle greenhouse emissions.** A fission station emits no carbon dioxide from the reaction itself; its life-cycle emissions, covering mining, construction, fuel processing and waste, are about $12\,\mathrm{g}$ of carbon dioxide equivalent per $\mathrm{kW\,h}$ — comparable with wind and about 70 times below coal (4D).
- **Reliable, on-demand supply.** Fission stations generate close to full power day and night, in any weather, with capacity factors above $90\,\%$ in the best fleets (4D).
- **A proven technology.** Fission is already established: 441 power reactors operable in 31 countries supply about $9\,\%$ of the world's electricity (4C).

Risks of fission for society.

- **Accidents are rare but serious.** Three accidents dominate the record, and each is worth knowing precisely, because they were different in cause:

Accident	Date	What happened	Consequences
Three Mile Island (USA)	1979	Equipment failure and operator error let cooling water escape; part of the core melted	A small release of radioactive gas; no confirmed health effects
Chernobyl (Ukraine)	1986	During a test, a flawed	31 workers and

Accident	Date	What happened	Consequences
		reactor design allowed the power to surge; the reactor exploded and its graphite caught fire	firefighters died within weeks of acute radiation sickness; hundreds of thousands of people were relocated from contaminated areas
Fukushima Daiichi (Japan)	2011	A magnitude-9 earthquake and the tsunami that followed cut all power and cooling; decay heat melted three cores	No confirmed deaths or radiation sickness from the radiation; around 150 000 residents were evacuated

Source: World Nuclear Association, The Chernobyl Accident, retrieved 2026-08-18. Source: World Nuclear Association, Fukushima Daiichi Accident, retrieved 2026-08-18. Source: World Nuclear Association, Three Mile Island, retrieved 2026-08-18.

Notice the physics inside the table. At Three Mile Island and Fukushima the chain reaction stopped when it should — the hazard came from the *decay heat* of the unstable fission fragments, which keeps producing energy after shutdown and must be cooled for days and weeks. At Chernobyl the reactor itself was destroyed. In every case the public hazard was the same: radioactive material escaping from damaged fuel into the surroundings.

- **Long-lived radioactive waste.** Spent fuel contains fragments and other nuclei with half-lives up to thousands of years and more — ^{239}Pu itself has a half-life of 24 100 years — so it must be isolated from the biosphere on geological timescales, and no country yet operates a permanent deep repository for power-reactor waste (4D).
- **Weapons proliferation.** The ^{239}Pu bred in reactors is a weapons-usable material, which is why spent fuel and plutonium stocks are counted and inspected under international safeguards.
- **Cost and time.** New fission builds in Western countries have finished years late and far over budget, and Australian cost studies estimate new nuclear as the most expensive new generation option in Australia (4D).

Benefits of fusion for society.

- **An almost inexhaustible fuel.** Deuterium is drawn from seawater, and tritium is bred from lithium inside the machine; the fuel supply is far larger than any foreseeable demand.
- **No runaway.** Fusion has no chain reaction (4C). The fuel fuses only while the temperature and the confinement are maintained; if either fails, the plasma cools or escapes and the reaction stops at once. A fusion machine cannot run away in the way an uncontrolled fission chain reaction can.
- **No long-lived fission-fragment waste.** The direct product, helium, is stable, and no fission fragments are created.
- **No carbon dioxide from the reaction**, and low life-cycle emissions, as for fission.

Risks and limitations of fusion for society.

- **It does not work yet, as a power source.** After decades of research no fusion machine has generated electricity; the engineering problems — holding a plasma at over 100 000 000 K continuously, breeding tritium, surviving the neutron bombardment — remain unsolved (4C).
- **Radioactive waste still appears.** The fusion neutrons activate the reactor walls — they make the wall materials radioactive — producing short- to medium-lived waste that must be managed, even though it is far less long-lived than spent fission fuel (4C).
- **The fuel tritium is itself radioactive** (β^-, 12.3-year half-life) and must be bred, contained and recycled without leaking.
- **Enormous upfront cost.** Research machines such as ITER cost billions of public money and years of international construction before any electricity is possible.

The comparison, side by side.

Feature	Fission	Fusion
Specific reactions used	^{235}U (slow neutrons); ^{239}Pu (fast neutrons)	deuterium–tritium on Earth; proton–proton chain in stars
Energy per kilogram of fuel	about 8.2×10^{13} J (^{235}U)	about 3.4×10^{14} J, roughly 4 times fission
Fraction of fuel mass converted	about 0.1 %	about 0.4 %
Fuel availability	Mined uranium; finite, but extendable by breeding ^{239}Pu from ^{238}U	Deuterium from seawater; tritium bred from lithium — far larger than foreseeable demand
Can the reaction run away?	An uncontrolled chain reaction can	No — the reaction stops at once if conditions fail
Long-lived radioactive waste	Yes — fragments with half-lives of thousands of years	No long-lived fragments; activated walls are short- to medium-lived
Greenhouse emissions in operation	None; life-cycle about 12 g per kW h	None; life-cycle low
Status as a power source	Proven — 441 reactors in 31 countries supply about 9 % of the world's electricity	Research stage — no machine has yet generated electricity

Whether fission is viable *for Australia in particular* — given this country's legal prohibitions, its costs, its renewable resources and its uranium reserves — is the separate investigation of 4D. This option asks the wider question: as power sources for society, each has genuine strengths and genuine costs, and the honest comparison is made with numbers, not slogans.

Worked examples

Example 1 — scaffolded

The deuterium–tritium reaction releases 17.6 MeV. Show that 1.0 kg of deuterium–tritium fuel, fully reacted, releases about 3.4×10^{14} J — the figure quoted in 4C. (Use $1\,\text{MeV}=1.60\times10^{-13}$ J, molar masses of 2 and 3 g mol^{-1}, and Avogadro's number $6.022\times10^{23}\,\text{mol}^{-1}$.)

Working	Comment
(a) Energy per reaction $=17.6\times1.60\times10^{-13}=2.82\times10^{-12}$ J.	Convert MeV to joules (4A).
(b) One reaction consumes one deuterium nucleus ($2\,\text{g mol}^{-1}$) and one tritium nucleus ($3\,\text{g mol}^{-1}$): a pair has molar mass $5\,\text{g mol}^{-1}$.	The reactants of the D–T reaction.
Number of pairs in $1.0\,\text{kg}=1000\,\text{g}$: $n=\frac{1000}{5}=200\,\text{mol}$, so $N=200\times6.022\times10^{23}=1.20\times10^{26}$ reactions.	Count the reactions available in the kilogram.
(c) $E=1.20\times10^{26}\times2.82\times10^{-12}=3.4\times10^{14}$ J.	Energy = number of reactions × energy per reaction.

∴ 1.0 kg of deuterium–tritium fuel releases about 3.4×10^{14} J, roughly 4 times the 8.2×10^{13} J from 1.0 kg of ^{235}U (4D).

Example 2 — scaffolded

The Sun radiates energy into space at 3.8×10^{26} W, all of it from the proton–proton chain, which releases 26.7 MeV each time it runs.

Source: NASA Science, Sun facts, retrieved 2026-08-18.

(a) Calculate the energy released each time the chain runs, in joules. (b) Calculate how many chains run each second. (c) Calculate the mass of hydrogen fused each second, and compare your answer with the published figure of about 6×10^{8} tonnes per second. (Mass of a proton $= 1.67 \times 10^{-27}$ kg.)

Working	Comment
(a) $E = 26.7 \times 1.60 \times 10^{-13} = 4.27 \times 10^{-12}$ J.	Convert MeV to joules.
(b) Chains per second $= \dfrac{3.8 \times 10^{26}}{4.27 \times 10^{-12}} = 8.9 \times 10^{37}$.	Power is energy per second; divide by the energy per chain.
(c) Each chain consumes 4 protons: $m = 8.9 \times 10^{37} \times 4 \times 1.67 \times 10^{-27} = 5.9 \times 10^{11}$ kg.	Mass = chains × protons per chain × proton mass.
5.9×10^{11} kg $\approx 6 \times 10^{8}$ tonnes, matching the published figure.	1 tonne = 1000 kg.

∴ the Sun fuses about 6×10^{8} tonnes of hydrogen every second. Of that mass, about 4×10^{6} tonnes is converted into energy each second, as 4A found from $\Delta E = \Delta m c^{2}$; the rest becomes helium.

Example 3 — unscaffolded

ITER is designed to produce 500 MW of fusion power — that is, 5.0×10^{8} J released by deuterium–tritium fusion every second. Each reaction consumes one tritium nucleus, and the machine's blanket is designed to breed one replacement tritium nucleus, from lithium-6, for each neutron released.

Source: ITER Organization, https://www.iter.org, retrieved 2026-08-18.

(a) Calculate the number of fusion reactions each second at full design power. (b) Calculate the mass of tritium the machine would consume in one day of full-power operation. (c) Calculate the mass of lithium-6 needed to breed that tritium. (Molar masses: tritium 3 g mol^{-1}, lithium-6 6 g mol^{-1}; Avogadro's number $6.022 \times 10^{23}\text{ mol}^{-1}$; $1\text{ MeV} = 1.60 \times 10^{-13}$ J.)

Each reaction releases $17.6\text{ MeV} = 2.82 \times 10^{-12}$ J, so

(a) number of reactions each second $= \dfrac{5.0 \times 10^{8}}{2.82 \times 10^{-12}} = 1.77 \times 10^{20}$.

(b) Reactions in one day $= 1.77 \times 10^{20} \times 86\,400 = 1.53 \times 10^{25}$, which is

$$n = \frac{1.53 \times 10^{25}}{6.022 \times 10^{23}} = 25.4\text{ mol}$$

of tritium atoms, a mass of $25.4 \times 3 = 76$ g.

(c) Breeding one tritium needs one lithium-6 nucleus, so the lithium-6 amount is also 25.4 mol, a mass of $25.4 \times 6 = 152$ g.

∴ a full-power ITER would consume about 76 g of tritium and about 152 g of lithium-6 per day — under a quarter of a kilogram of fuel in total. For comparison, a coal-fired boiler delivering the same 500 MW of thermal power would burn about 1700 tonnes of black coal in the same day (at 25 MJ kg^{-1}, as used in 4D): several million times more mass.

Example 4 — unscaffolded

A media article claims: *"Because a fusion reaction can never run away, a fusion power station would pose no risk at all to people living near it."* Evaluate this claim using the physics of this subtopic.

This is a reasoning task. Marks are awarded for the quality of the evaluation, not for whether the final stance is positive or negative. A full response:

Identify what is true in the claim. Fusion has no chain reaction: each event consumes its two nuclei and releases nothing that triggers the next one (4C). If the plasma cools, or the confinement fails, the reaction stops at once — so the specific failure mode of fission, an uncontrolled chain reaction or uncooled decay heat melting the core, has no fusion equivalent. In that limited sense the claim is correct.

Identify what is false in it. "No risk at all" is an absolute that no real energy system meets. A fusion station would still hold a stock of tritium, a radioactive gas (β^-, 12.3-year half-life), which must be bred, contained and recycled without leaking. Its neutrons activate the reactor walls, making them radioactive, so the station still produces waste — short- to medium-lived, but waste that must be handled and stored (4C). And it remains a large industrial facility, with the ordinary hazards of any power station.

Reach a measured conclusion. The defensible claim is not "no risk" but "different, and in several important ways smaller, risks": no runaway reaction, no long-lived fission-fragment waste, but a radioactive fuel inventory and activated materials that still require management. The article's physics is half right, and its conclusion overstates what that half supports.

Practice questions

Question 1 The net reaction of the proton–proton chain is

$$4\ {}^{1}_{1}\text{H} \rightarrow {}^{A}_{Z}X + 2\ {}^{0}_{+1}\text{e} + \text{energy}.$$

(a) Find A and Z, and identify the nucleus X.
(b) State how many protons are consumed and how many of the reaction's products carry charge.
(c) The chain releases about $26.7\ \text{MeV}$. Convert this energy to joules.

Question 2 The deuterium–tritium reaction is

$${}^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + {}^{1}_{0}\text{n} + \text{energy}.$$

(a) Verify that both nucleon number and charge are conserved.
(b) Of the $17.6\ \text{MeV}$ released, $14.1\ \text{MeV}$ is carried by the neutron. Calculate the neutron's share as a percentage.
(c) Explain why the neutron, rather than the helium, is the product that breeds fresh tritium in the blanket.

Question 3 One possible fission of ${}^{235}\text{U}$ is

$${}^{1}_{0}\text{n} + {}^{235}_{92}\text{U} \rightarrow {}^{140}_{54}\text{Xe} + {}^{A}_{Z}X + 2\ {}^{1}_{0}\text{n} + \text{energy}.$$

(a) Find A and Z, and identify the element X.
(b) Each fission releases about $200\ \text{MeV}$. Convert this energy to joules.
(c) State which of the products of this reaction carry most of the released energy, and name the form in which they carry it.

Question 4 The formation of plutonium-239 begins when uranium-238 absorbs a neutron. (a) Complete the absorption equation: ${}^{1}_{0}\text{n} + {}^{238}_{92}\text{U} \rightarrow ?$ (b) The product then decays by β^- emission. Complete: ${}^{239}_{92}\text{U} \rightarrow ? + {}^{0}_{-1}\text{e}$. (c) The daughter of (b) decays again by β^- emission. Complete the equation and name the final product. (d) State the property of the final product that makes it useful as a reactor fuel.

Question 5 The energy chain of a fission power station runs: nuclear energy → kinetic energy of the fragments → thermal energy of the core → thermal energy of the steam → kinetic energy of the turbine → electrical energy. Copy this chain into your logbook and, beside each arrow, name the part of the station where that transfer or transformation happens. Then answer: what happens to the roughly two thirds of the thermal energy that does not become electrical energy?

Question 6 In one deuterium–tritium reaction, $17.6\,\text{MeV}$ is released. (a) Calculate the mass converted into energy in one reaction, using $\Delta m = \Delta E / c^2$ with $c = 3.00 \times 10^8\,\text{m s}^{-1}$. (b) The reactants contain 5 nucleons in total. Taking each nucleon as $1.67 \times 10^{-27}\,\text{kg}$, calculate the total mass of the reactants. (c) Calculate the fraction of the fuel mass that is converted into energy, as a percentage.

Question 7 Suppose $1.0\,\text{kg}$ of hydrogen were fused completely by the proton–proton chain, each run of the chain consuming four protons and releasing $26.7\,\text{MeV}$. (a) Calculate the number of times the chain runs. (Molar mass of hydrogen $1\,\text{g mol}^{-1}$; Avogadro's number $6.022 \times 10^{23}\,\text{mol}^{-1}$.) (b) Calculate the total energy released, and compare it with the $3.4 \times 10^{14}\,\text{J}$ released by $1.0\,\text{kg}$ of deuterium–tritium fuel. (c) Suggest why, despite releasing more energy per kilogram than any other fuel, proton–proton fusion will never be used in a power station on Earth.

Question 8 Power stations on Earth pursue deuterium–tritium fusion rather than the proton–proton chain that powers the Sun. Explain this choice, referring to the first step of the proton–proton chain and to the temperatures involved.

Question 9 ITER is designed to produce $500\,\text{MW}$ of fusion power. This question models the machine running at that power, continuously, for one full year — a model, since ITER will operate in pulses. (a) Calculate the number of deuterium–tritium reactions in the year. (b) Calculate the mass of tritium consumed. (Molar mass $3\,\text{g mol}^{-1}$.) (c) Calculate the mass of lithium-6 needed to breed that tritium. (Molar mass $6\,\text{g mol}^{-1}$.) (d) Comment on the fuel mass your answers imply, compared with the fuel mass of a fission or coal station of the same power.

Question 10 Today's power reactors use slow neutrons to fission ^{235}U; fast reactors running on ^{239}Pu use fast neutrons. (a) Explain why a ^{235}U reactor needs a moderator. (b) Explain why a fast reactor must not have one.

Question 11 Fission fragments are unstable. (a) Explain why the fragments of a heavy nucleus such as uranium are neutron-rich, referring to what holds a heavy nucleus together (3A). (b) Name the type of radiation the fragments mostly emit as they decay, and the radiation that often accompanies it (3B). (c) Explain why spent fuel rods, removed from a reactor, are still hot and still dangerous, even though the chain reaction has stopped.

Question 12 The fission of ^{239}Pu releases about $200\,\text{MeV}$ per fission. (a) Convert this energy to joules. (b) Calculate the number of ^{239}Pu atoms in $1.0\,\text{kg}$. (Molar mass $239\,\text{g mol}^{-1}$; Avogadro's number $6.022 \times 10^{23}\,\text{mol}^{-1}$.) (c) Hence calculate the energy released by the complete fission of $1.0\,\text{kg}$ of ^{239}Pu. (d) Compare your answer with the $3.4 \times 10^{14}\,\text{J}$ released by $1.0\,\text{kg}$ of deuterium–tritium fuel, and state which fuel is more energy-dense per kilogram.

Question 13 Natural uranium is $99.3\,\%$ ^{238}U, and a conventional reactor fissions mainly the $0.7\,\%$ that is ^{235}U. (a) Explain how breeding ^{239}Pu from ^{238}U could make the same mined uranium supply yield many times more energy. (b) State one reason why separated plutonium is counted and inspected under international safeguards.

Question 14 This question uses a deliberately simplified model of a coastal fission station; the numbers are chosen for the model and are not measurements. In the model, the reactor produces $3.0\,\text{GW}$ of thermal power and the station converts $33\,\%$ of it into electrical energy; the waste heat is carried away by seawater, whose temperature must rise by no more than $8.0\,\text{K}$. (Specific heat capacity of seawater: $4200\,\text{J kg}^{-1}\,\text{K}^{-1}$.) (a) Calculate the electrical power delivered. (b) Calculate the waste heat transferred to the seawater each second. (c) Calculate the mass of seawater that must flow through the condenser each second. (d) Explain why transferring this energy to the sea is not a design failure but an unavoidable part of running a thermal power station.

Question 15 The three major reactor accidents — Three Mile Island (1979), Chernobyl (1986) and Fukushima Daiichi (2011) — had different causes. (a) Identify the event that initiated each accident. (b) Identify what all three had in common: what, physically, created the hazard to the public? (c) At Three Mile Island and Fukushima the chain reaction stopped as designed. Explain what kept producing energy in the core afterwards, and why that energy had to be removed.

Question 16 Test each side by the same standard. (a) Give one genuine benefit to society of fission power and one of fusion power. (b) Give one genuine risk to society of fission power and one of fusion power. (c) Identify one risk or cost that the two share. (Give real strengths and real weaknesses on both sides — not a straw man.)

Question 17 The study design's option introduction invites a comparison of "the percentage of the mass that is transformed into energy". (a) For fission: $200\,\text{MeV}$ is released from reactants of about 236 nucleons. Taking each nucleon as 1.67×10^{-27} kg, calculate the fraction of mass converted, as a percentage. (b) For deuterium–tritium, Question 6 found about $0.4\,\%$. For the proton–proton chain, $26.7\,\mathrm{MeV}$ is released from four protons. Calculate the fraction converted, as a percentage. (c) Use the binding energy curve (4A) to explain why fusion converts a larger fraction of its fuel's mass than fission does.

Question 18 A newspaper headline reads: *"Fusion: the power source that never runs out of fuel and can never melt down."* Evaluate both halves of this claim using the physics of this subtopic. In your answer, test the strongest form of each half before you judge it.

Answers

Question 1 (a) $A = 4$, $Z = 2$: helium-4; (b) 4 protons consumed; 3 charged products (the helium nucleus and two positrons); (c) 4.3×10^{-12} J. **Question 2** (a) Nucleons: $2 + 3 = 4 + 1$; charges: $1 + 1 = 2 + 0$; (b) $80\,\%$; (c) the neutron escapes the plasma and is absorbed in the lithium blanket, where it breeds tritium; the charged helium is confined within the plasma. **Question 3** (a) $A = 94$, $Z = 38$: strontium; (b) 3.2×10^{-11} J; (c) the two fragments, carrying about $85\,\%$ of the energy as kinetic energy. **Question 4** (a) $^{239}_{92}$U; (b) $^{239}_{93}$Np; (c) $^{239}_{93}\text{Np} \rightarrow {}^{239}_{94}\text{Pu} + {}^{0}_{-1}\text{e}$ — plutonium-239; (d) it is fissile — it can sustain a chain reaction. **Question 5** Core (nuclear → kinetic → thermal); coolant and steam generator (thermal transferred to water and boiled); turbine (thermal → kinetic); generator (kinetic → electrical); condenser (waste heat out). The remaining two thirds is transferred to the surroundings as waste heat, via cooling towers, a river or the sea. **Question 6** (a) 3.1×10^{-29} kg; (b) 8.4×10^{-27} kg; (c) about $0.37\,\%$ ($\approx 0.4\,\%$). **Question 7** (a) 1.5×10^{26} chains; (b) 6.4×10^{14} J — about 1.9 times the D–T figure; (c) its first step is extraordinarily unlikely, governed by the weak nuclear force, so it proceeds usefully only in stellar cores. **Question 8** See solution — D–T fuses at achievable temperatures; the p–p chain's first step is too slow to ever produce useful power on Earth. **Question 9** (a) 5.6×10^{27} reactions; (b) about 28 kg of tritium; (c) about 56 kg of lithium-6; (d) see solution — tens of kilograms of fusion fuel per year, against about 190 kg of uranium-235 or about 630 000 tonnes of black coal. **Question 10** (a) Slow neutrons are far more likely to be absorbed by ^{235}U and start a fission, so the moderator slows the fast fission neutrons; (b) a fast reactor's chain reaction is carried by fast neutrons fissioning ^{239}Pu; a moderator would slow them and defeat the design. **Question 11** (a) Heavy nuclei need proportionally more neutrons than protons to be stable; the fragments inherit that neutron-richness for their smaller size; (b) β^-, often accompanied by γ; (c) the unstable fragments keep decaying and releasing energy (decay heat) on timescales from days to thousands of years. **Question 12** (a) 3.2×10^{-11} J; (b) 2.5×10^{24} atoms; (c) 8.0×10^{13} J; (d) D–T fuel releases about 4 times as much per kilogram. **Question 13** (a) ^{238}U is $99.3\,\%$ of the uranium; converting it to fissile ^{239}Pu lets that vast majority be used as fuel, not just the $0.7\,\%$; (b) ^{239}Pu is a material from which nuclear weapons can be made, so it must be accounted for to prevent diversion. **Question 14** (a) 1.0 GW; (b) 2.0×10^{9} J each second; (c) 6.0×10^{4} kg each second; (d) see solution — a thermal station cannot turn all its heat into electricity. **Question 15** (a) TMI: equipment failure and operator error; Chernobyl: a power surge during a test in a flawed reactor design; Fukushima: a magnitude-9 earthquake and tsunami that cut power and cooling; (b) radioactive material escaping from damaged fuel; (c) decay heat from the unstable fission fragments; without cooling it melts the fuel. **Question 16** Model points in the solution; award real strengths and weaknesses on both sides. **Question 17** (a) about $0.09\,\%$; (b) about $0.7\,\%$; (c) see solution — fusion starts further from the curve's peak. **Question 18** See solution — the fuel half is essentially true; the meltdown half is true but incomplete, because a fusion station still holds tritium and produces activated waste.

Fully-worked solutions

Question 1 (a) Nucleon number: $4 \times 1 = A + 0$, so $A = 4$. Charge: $4 \times 1 = Z + 2 \times 1$, so $Z = 2$, which is helium: the nucleus is $^{4}_{2}$He. (b) Four protons are consumed. The charged products are the helium-4 nucleus and the two positrons — three charged products in all. (The neutrinos, omitted here, carry no charge.) (c) $26.7\text{ MeV} = 26.7 \times 1.60 \times 10^{-13} = 4.3 \times 10^{-12}\text{ J}$.

Question 2 (a) Nucleon numbers: $2 + 3 = 5$ on the left; $4 + 1 = 5$ on the right. Charges: $1 + 1 = 2$ on the left; $2 + 0 = 2$ on the right. Both are conserved. (b) $\frac{14.1}{17.6} = 0.80 = 80\,\%$. (c) The neutron carries no charge, so it is not confined by the magnetic fields holding the plasma; it escapes into the surrounding blanket, where it is absorbed by lithium-6 to breed tritium. The helium nucleus is positively charged and stays within the plasma, where its energy helps keep the plasma hot.

Question 3 (a) Nucleons: $1 + 235 = 140 + A + 2$, so $A = 94$. Charges: $0 + 92 = 54 + Z + 0$, so $Z = 38$, which is strontium: $^{94}_{38}$Sr. (b) $200\text{ MeV} = 200 \times 1.60 \times 10^{-13} = 3.2 \times 10^{-11}\text{ J}$. (c) The two fission fragments carry most of the energy — about $85\,\%$ — as kinetic energy; it is their collisions with the surrounding atoms that heat the core (as used in Question 5).

Question 4 (a) ${}^{1}_{0}n + {}^{238}_{92}U \rightarrow {}^{239}_{92}U$ — the nucleus keeps its 92 protons and gains one nucleon. (b) In β^{-} decay a neutron becomes a proton, so Z rises by one: ${}^{239}_{92}U \rightarrow {}^{239}_{93}Np + {}^{0}_{-1}e$. The daughter is neptunium-239. (c) ${}^{239}_{93}Np \rightarrow {}^{239}_{94}Pu + {}^{0}_{-1}e$. The final product is plutonium-239. (d) ${}^{239}Pu$ is fissile: absorbing a neutron can fission it, and the neutrons released can sustain a chain reaction (4B), so it can serve as a reactor fuel.

Question 5 Beside each arrow: - nuclear → kinetic of fragments: the reactor core (the fuel itself); - kinetic → thermal of the core: the reactor core (fragments colliding with surrounding atoms); - thermal of the core → thermal of the steam: the coolant loop and the steam generator; - thermal of the steam → kinetic of the turbine: the turbine; - kinetic of the turbine → electrical: the generator. About two thirds of the thermal energy never becomes electrical energy. It is transferred to the surroundings as waste heat: the spent steam is condensed, and the energy is carried away by cooling towers, a river, or the sea. This is a consequence of how every thermal station converts heat into work, not a defect of nuclear stations in particular (4D).

Question 6 (a) $\Delta E = 17.6 \times 1.60 \times 10^{-13} = 2.82 \times 10^{-12}$ J, so

$$\Delta m = \frac{\Delta E}{c^2} = \frac{2.82 \times 10^{-12}}{(3.00 \times 10^{8})^2} = 3.1 \times 10^{-29}\,\text{kg}.$$

(b) $5 \times 1.67 \times 10^{-27} = 8.4 \times 10^{-27}\,\text{kg}$. (c) Fraction $= \dfrac{3.1 \times 10^{-29}}{8.4 \times 10^{-27}} = 3.7 \times 10^{-3}$, about $0.37\,\%$ — roughly $0.4\,\%$.

Question 7 (a) $1.0\,\text{kg}$ of hydrogen is $1000\,\text{mol}$ of hydrogen atoms, i.e. $1000 \times 6.022 \times 10^{23} = 6.022 \times 10^{26}$ protons. Each chain consumes four, so the number of chains is

$$\frac{6.022 \times 10^{26}}{4} = 1.5 \times 10^{26}.$$

(b) $E = 1.5 \times 10^{26} \times 4.27 \times 10^{-12} = 6.4 \times 10^{14}$ J. This is about 1.9 times the 3.4×10^{14} J from $1.0\,\text{kg}$ of deuterium–tritium fuel: proton–proton fusion is the most energy-dense reaction of the three, per kilogram. (c) The chain's first step — two protons fusing — is governed by the weak nuclear force and is extraordinarily unlikely. Even in the Sun's core it proceeds only because the Sun is enormous and can wait billions of years. No machine on Earth, with kilograms of fuel, could make this step proceed fast enough to produce useful power.

Question 8 The proton–proton chain begins with two bare protons fusing. That step is governed by the weak nuclear force and is so unlikely that it proceeds at a useful rate only under the enormous density and confinement of a stellar core, sustained for billions of years. Deuterium and tritium nuclei, by contrast, fuse far more readily: their reaction proceeds at the tens-to-hundreds of millions of kelvin that machines such as ITER are designed to reach (4C). So although proton–proton fusion releases more energy per kilogram (Question 7), deuterium–tritium is the only fusion reaction practical for a power station on Earth.

Question 9 One year is $365 \times 24 \times 3600 = 3.1536 \times 10^{7}$ s. (a) Each reaction releases 2.82×10^{-12} J, so the reactions per second are $5.0 \times 10^{8} / 2.82 \times 10^{-12} = 1.77 \times 10^{20}$, and in the year

$$1.77 \times 10^{20} \times 3.1536 \times 10^{7} = 5.6 \times 10^{27}\,\text{reactions}.$$

(b) Each reaction consumes one tritium nucleus, so the tritium amount is

$$n = \frac{5.6 \times 10^{27}}{6.022 \times 10^{23}} = 9.3 \times 10^{3}\,\text{mol},$$

a mass of $9.3 \times 10^{3} \times 3 \approx 28\,\text{kg}$. (c) Breeding is one-for-one, so the lithium-6 amount is the same number of moles, a mass of $9.3 \times 10^{3} \times 6 \approx 56\,\text{kg}$. (d) A full-power year consumes about $84\,\text{kg}$ of fusion fuel in total. A fission station producing the same thermal power fissions

$$\frac{5.0 \times 10^{8} \times 3.1536 \times 10^{7}}{8.2 \times 10^{13}} \approx 190\,\text{kg}$$

of uranium-235 in the same year (at 8.2×10^{13} J per kilogram, from 4D) — more than twice the fusion fuel mass, even though the fusion figure includes the lithium used to breed the tritium — and a coal-fired boiler of the same thermal power would burn about $630\,000$ tonnes of black coal (at $25\,\text{MJ kg}^{-1}$, as used in 4D). Fusion fuel's energy density is the largest of any fuel considered in this book.

Question 10 (a) A slow neutron is far more likely to be absorbed by a ^{235}U nucleus — and absorption is what starts the fission. The neutrons released by fission are fast, so a ^{235}U reactor includes a moderator to slow them by repeated collisions, making the next fission likely (4B). (b) In a fast reactor the chain reaction is carried by fast neutrons initiating fission of ^{239}Pu. A moderator would slow those neutrons, which is the opposite of the design's purpose — so a fast reactor contains no moderator at all.

Question 11 (a) A heavy nucleus needs proportionally more neutrons than protons to be stable: the extra neutrons add strong-nuclear-force attraction without adding electrostatic repulsion between protons (3A). When the nucleus splits, each fragment inherits that neutron-to-proton ratio, but at its smaller size the ratio is too high — the fragment is neutron-rich and therefore unstable. (b) Neutron-rich nuclei move toward stability by β^- decay (3B), so the fragments mostly emit beta-minus particles; gamma rays often follow as the daughter nucleus settles to a lower energy state. (c) The fragments keep decaying after the chain reaction stops, and each decay releases energy — this is decay heat. It continues on timescales from days (iodine-131) through decades (strontium-90, caesium-137) to thousands of years, so spent fuel remains hot enough to need cooling and radioactive enough to need shielding.

Question 12 (a) $200\,\text{MeV} = 200 \times 1.60 \times 10^{-13} = 3.2 \times 10^{-11}$ J. (b) $1.0\,\text{kg}$ of ^{239}Pu is $1000/239 = 4.18\,\text{mol}$, containing

$$4.18 \times 6.022 \times 10^{23} = 2.5 \times 10^{24}\ \text{atoms}.$$

(c) $E = 2.5 \times 10^{24} \times 3.2 \times 10^{-11} = 8.0 \times 10^{13}$ J. (d) Deuterium–tritium fuel releases 3.4×10^{14} J per kilogram — about $3.4 \times 10^{14} / 8.0 \times 10^{13} \approx 4.3$ times as much. Fusion fuel is the more energy-dense per kilogram; both fission fuels sit near $8 \times 10^{13}\,\text{J kg}^{-1}$.

Question 13 (a) Only $0.7\,\%$ of natural uranium is fissile ^{235}U; the other $99.3\,\%$, ^{238}U, mostly absorbs neutrons without fissioning. But absorbing a neutron converts ^{238}U through two β^- decays into ^{239}Pu, which is fissile. A breeder reactor does this deliberately, turning the vast ^{238}U majority of the fuel into new fuel as it runs, so the same mined uranium can ultimately yield many times more energy than a conventional reactor extracts from its $0.7\,\%$. (b) ^{239}Pu is one of the materials from which nuclear weapons can be made. Counting and inspecting separated plutonium and spent fuel under international safeguards verifies that the material stays in peaceful use and is not diverted to weapons.

Question 14 (a) Electrical power $= 0.33 \times 3.0 = 1.0\,\text{GW}$. (b) Waste heat $= 3.0 - 1.0 = 2.0\,\text{GW}$, so 2.0×10^9 J is transferred to the seawater each second. (c) With $Q = mc\Delta T$ (2B), the mass flowing each second is

$$m = \frac{Q}{c\Delta T} = \frac{2.0 \times 10^9}{4200 \times 8.0} = 6.0 \times 10^4\,\text{kg},$$

about 60 tonnes of seawater every second. (d) A thermal station converts heat into electrical energy through a turbine, and no such machine can turn all of its thermal energy into work: the model's $33\,\%$ efficiency is typical (4D). The remaining two thirds must be transferred somewhere, and the condenser and cooling water are where that happens. This is true of coal and gas stations as well; the sea receives waste heat from every coastal thermal station, whatever its fuel.

Question 15 (a) Three Mile Island: equipment failure combined with operator error let cooling water escape, uncovering part of the core. Chernobyl: during a test, a flawed reactor design allowed the power to surge; the reactor exploded and its graphite burned. Fukushima Daiichi: a magnitude-9 earthquake and the tsunami that followed cut all electrical power and cooling. (b) In all three, the hazard to the public was the same physical thing: radioactive material escaping from damaged fuel into the surroundings. (c) The unstable fission fragments kept decaying and releasing energy — decay heat. The chain reaction stops, but the fragments' decays continue, so energy keeps appearing in the core and must be carried away by cooling; if it is not, the fuel heats up and can melt, as it did at Fukushima.

Question 16 Award marks for genuine strengths and genuine weaknesses on both sides — not a straw man. Model points: (a) Fission benefit: a proven technology already supplying about 9% of the world's electricity, with low life-cycle emissions ($12\,\mathrm{g}$ per $\mathrm{kW\,h}$) and on-demand, high-capacity-factor output. Fusion benefit: an almost inexhaustible fuel (deuterium from seawater, tritium bred from lithium) and no runaway reaction — the reaction stops at once if the conditions fail. (b) Fission risk: long-lived radioactive waste that must be isolated on geological timescales, with no permanent repository yet operating anywhere. Fusion risk: it is not yet a power source — no machine has generated electricity, and the engineering problems remain unsolved; also, its neutrons activate the reactor walls and its tritium inventory is radioactive. (c) Shared: both produce radioactive material that must be managed (fission fragments for fission; activated wall materials and tritium for fusion); both need large capital investment and long construction times; both ultimately deliver their energy through the same steam-turbine machinery and its waste heat.

Question 17 (a) Reactant mass $\approx 236 \times 1.67 \times 10^{-27} = 3.94 \times 10^{-25}\,\mathrm{kg}$. Mass converted:

$$\Delta m = \frac{3.2 \times 10^{-11}}{(3.00 \times 10^{8})^{2}} = 3.6 \times 10^{-28}\,\mathrm{kg}.$$

Fraction $= \dfrac{3.6 \times 10^{-28}}{3.94 \times 10^{-25}} = 9.0 \times 10^{-4}$, about 0.09% — the "about 0.1%" quoted in 4D. (b) Reactant mass $= 4 \times 1.67 \times 10^{-27} = 6.68 \times 10^{-27}\,\mathrm{kg}$; $\Delta E = 4.27 \times 10^{-12}\,\mathrm{J}$, so

$$\Delta m = \frac{4.27 \times 10^{-12}}{(3.00 \times 10^{8})^{2}} = 4.7 \times 10^{-29}\,\mathrm{kg},$$

and the fraction is $\dfrac{4.7 \times 10^{-29}}{6.68 \times 10^{-27}} = 7.1 \times 10^{-3}$, about 0.7%. (c) The binding energy curve (4A) rises very steeply for the lightest nuclei and falls only slowly beyond the iron peak. Fusion starts at the very bottom of the curve — hydrogen isotopes at 1–$3\,\mathrm{MeV}$ per nucleon — and moves its nucleons a long way up toward the peak, so a large fraction of the mass is converted. Fission starts near $7.6\,\mathrm{MeV}$ per nucleon and moves its nucleons only to about $8.5\,\mathrm{MeV}$ per nucleon, a much shorter climb — so a much smaller fraction of the mass is converted. The further a reaction's starting point is from the peak, the larger the fraction of mass its products lose.

Question 18 Test each half in its strongest form, then judge.

The fuel half. In its strongest form: deuterium occurs naturally in seawater — about one hydrogen atom in 6500 — so the oceans hold a supply far beyond any foreseeable demand, and the tritium is not mined at all but bred inside the machine from lithium, a plentiful element. The strongest form is essentially true: on human timescales, D–T fusion fuel will not run out. (One qualification: the claim rests on breeding working reliably, which has not yet been demonstrated in a power station.)

The meltdown half. "Meltdown" is a fission failure mode: an uncontrolled chain reaction, or uncooled decay heat, melting the core. In its strongest form the fusion half is also true — fusion has no chain reaction, and if the temperature or the confinement fails the reaction simply stops; there is no core full of decaying fragments to melt. But the strongest form still does not mean "no hazard": a fusion station holds a radioactive tritium inventory that must be contained, and its neutrons activate the walls into radioactive material that must be managed.

Judgement. Both halves survive in their strong forms, so the headline is fair as far as it goes — but a careful evaluation adds that "never melts down" is not the same as "poses no risk", exactly the overstatement examined in Worked Example 4.

Option task (assessed) — house convention

This is the assessed Option task for Option 2.2. It is set in one of the study design's own Unit 2 Outcome 2 task formats — *a physics-referenced response to an issue* — and is marked against the five *Communicating physics* key knowledge dot points (U2.2.CP.1–.5), which are owned by 10A and 10B. The 30-mark total is **house convention**: the study design fixes no mark allocations at Units 1 & 2, all assessment is school-based, and the VCAA is told only whether the unit was completed satisfactorily. Your teacher sets the conditions; a written response of 1000–1500 words (or an equivalent scientific poster) is the expected scale.

The issue.

> A government science advisory board is reviewing low-emissions electricity options. It asks: *"Nuclear energy can come from fission — a technology that works today — or from fusion — a technology that does not yet work as a power source. Which deserves society's investment over the coming decades, and why?"*

Write a physics-referenced response to the board in which you compare fusion and fission as power sources and justify a position: fission, fusion, both, or neither.

Your response must

1. state what you mean by a source being *viable* — the frame you are judging by — and surface any assumptions built into the question (the treatment of *viable* as a contested term in 4D is the model);
2. present the physics of both sources with correct equations and numbers: the proton–proton chain and the deuterium–tritium reaction; fission of ^{235}U (slow neutrons) and ^{239}Pu (fast neutrons); energy per reaction and per kilogram of fuel; the fraction of fuel mass converted into energy; and the availability of each fuel;
3. include at least one data representation — a comparison table or graph — organising your evidence, and state at least one limitation of the comparison it shows;
4. weigh the risks and benefits for society of each source, using real, named, dated evidence (for example: the accidents of 1979, 1986 and 2011; waste half-lives; life-cycle emissions; fuel supply), and evaluate the validity of each source you cite;
5. discuss at least one sociocultural, economic, legal or political factor relevant to the issue (for Australia, 4D supplies the legal and cost context);
6. end with a justified position and at least one limitation of your own evidence.

Marking rubric — 30 marks, keyed to the Communicating physics dot points.

Marks are awarded for the quality of the reasoning, not the conclusion reached. A well-argued case for fission, for fusion, for both, or for neither can each receive full marks.

Criterion	Study design dot point	Marks
1. Validity of sources	"evaluate validity of sources of information"	6
2. Physics concepts and terminology	"apply physics concepts specific to the investigation: definitions of key terms; and use of appropriate scientific terminology, conventions and representations"	6
3. Data representations and limitations	"apply the use of data representations, models and theories in organising and explaining observed phenomena and physics concepts, and discuss the limitations of the explanations"	6
4. Societal factors	"discuss the influence of sociocultural, economic, legal and political factors relevant to the selected issue or application"	6
5. Justified stance	"apply physics understanding to justify a stance, opinion or solution to the selected issue or application"	6

Descriptors per criterion:

- **5–6 marks** — Criterion 1: several named, dated, authoritative sources are used, and at least one is explicitly evaluated for validity (who publishes it, what it measures, what it does not). Criterion 2: the named reactions are written with correct, balanced equations; the energy figures, fuel-availability facts and fraction-of-mass-converted comparison are correct; key terms (*fissile*, *plasma*, *viable*, …) are defined at first use. Criterion 3: a table or graph genuinely organises the comparison, and a real limitation of it is stated (what it leaves out, or what its numbers do not measure). Criterion 4: at least one social, economic, legal or political factor is discussed as physics-relevant evidence, not as an aside. Criterion 5: the position follows from the physics presented — each reason given is a physics reason with evidence attached.
- **3–4 marks** — the criterion is met in substance but with a gap: a source used without evaluation; a correct comparison with a minor physics slip or an undefined term; a data representation with no stated limitation; a societal factor named but not discussed; a position stated with partial support from the physics.
- **1–2 marks —** the criterion is attempted but thin: one weak or undated source; physics stated with significant errors; a decorative rather than organising representation; societal factors absent or asserted; a position asserted rather than argued.
- **0 marks** — the criterion is not addressed.

Chapter 10 Options: communicating physics, climate, nuclear and medical physics — 10E Option 2.6: How is radiation used to maintain human health?

Scope — *VCE Physics Study Design, Unit 2, Area of Study 2, Option 2.6 — The physics of medical radiation*: - “describe how X-rays for medical use are produced including the distinction between soft and hard X-rays” - “describe how medical radioisotopes may be produced by neutron bombardment and high energy collisions” - “compare ionising and non-ionising radiation with reference to how each affects living tissues and cells” - “compare the processes of, and images produced by, medical imaging using two or more of X-rays, computed tomography (CT), γ radiation, magnetic resonance imaging (MRI), single photon emission computed tomography (SPECT) and positron emission tomography (PET)” - “describe applications of medical radioisotopes in imaging and diagnosis” - “relate the detection and penetrating properties of α, β and γ radiation to their use in different medical applications”

The five Communicating physics dot points printed under this option are owned once, in Sections 10A and 10B; the Option task at the end of this section assesses them.

Theory

Chapter 3 met radiation from the nucleus first as a hazard — Section 3E studied what α, β and γ radiation do to the human body — and then as a treatment, when Section 3F used that same physics to destroy diseased tissue. This option turns to the third great use of radiation in medicine: **finding out what is wrong without cutting the patient open**. Imaging and diagnosis use X-rays (which do not come from the nucleus at all) as well as radioisotopes that emit γ, β^+ and other radiations. Along the way the option picks up the physics of how medical X-rays and medical radioisotopes are made in the first place, and the comparison between ionising and non-ionising radiation that sits behind every sensible choice of imaging technique.

Two Australian bodies appear throughout this section. ARPANSA (the Australian Radiation Protection and Nuclear Safety Agency, based in Melbourne) sets the radiation protection standards under which medical imaging operates (Section 3E). ANSTO (the Australian Nuclear Science and Technology Organisation) manufactures medical radioisotopes at its OPAL research reactor at Lucas Heights, New South Wales, and supplies them to hospitals around the country. Source: ANSTO, Medical radioisotopes, ansto.gov.au, retrieved 2026-08-18.

Diagnosis versus therapy. Keep the two jobs separate throughout this section:

- **Diagnosis** (imaging) means finding out what is happening inside the body — a broken bone, a blocked artery, a region of tissue working harder than it should. The radiation is a messenger: it must get from the region of interest to a detector, carrying information with it.
- **Therapy** means treating disease — above all, killing cancer cells. The radiation is a tool of destruction, and its job is to deposit energy in the diseased tissue (Section 3F).

The same property — how deeply each radiation penetrates matter (Section 3B) — decides which radiations suit which job.

How medical X-rays are produced. X-rays are electromagnetic waves of higher frequency and shorter wavelength than ultraviolet light (Section 1B). They are not emitted by nuclei; they are made in an **X-ray tube**. The tube contains:

- a heated filament (the **cathode**, negative electrode), which releases electrons because the heat gives some electrons enough energy to escape the metal — a process called **thermionic emission**;
- a high potential difference, typically tens of thousands of volts, between the cathode and the target;
- a metal target (the **anode**, positive electrode), usually tungsten, chosen because it has a very high melting point.

Each released electron is accelerated through the potential difference V. From Section 5A, the energy an electron gains is

$$E = qV$$

where q is the electron's charge ($e = 1.60 \times 10^{-19}$ C). An electron arriving at the target therefore carries a large kinetic energy. When it strikes the target, X-ray photons are produced in two ways:

1. **Deceleration.** As an electron passes near a target nucleus it is strongly deflected and slowed; the kinetic energy it loses is emitted as an X-ray photon. Electrons lose different amounts, so this process produces a continuous range of photon energies, up to a maximum equal to the electron's full kinetic energy.
2. **Electron transitions in the target atoms.** An incoming electron can knock an inner-shell electron out of a target atom. When an outer-shell electron drops down to fill the vacancy, the energy it loses is emitted as an X-ray photon of a definite energy characteristic of the target metal.

The energy accounting is striking: only about 1 % of the electrons' kinetic energy emerges as X-rays; the other 99 % becomes thermal energy in the target. That is why the anode is made of a metal with a very high melting point, is spun continuously so the beam strikes a fresh patch of metal, and is heavily cooled. Source: ARPANSA, Medical radiation exposure, retrieved 2026-08-18.

Soft and hard X-rays. Within the X-ray part of the spectrum, a useful distinction is drawn:

- **Soft X-rays** have lower photon energies (lower frequencies, longer wavelengths). They are less penetrating and are absorbed within a short distance of the body's surface.
- **Hard X-rays** have higher photon energies (higher frequencies, shorter wavelengths). They are far more penetrating and can pass right through the body.

Medical imaging needs the hard X-rays: only radiation that can pass through the body can reach a detector on the far side and form an image. The soft X-rays in the beam are useless for imaging — they are absorbed in the patient, adding dose without adding image — so the beam is passed through a thin filter (for example aluminium) that absorbs the soft component before the beam reaches the patient. Raising the tube's potential difference raises the maximum photon energy the tube can produce, giving a harder, more penetrating beam for thicker parts of the body.

How medical radioisotopes are produced. A **radioisotope** is a radioactive isotope — a nucleus with too many or too few neutrons to be stable (Section 3A). The radioisotopes used in medicine do not lie around waiting to be collected; they are manufactured by deliberately transforming stable nuclei. Both production routes apply exactly the conservation rules of Section 3B: mass number (top numbers) and charge (bottom numbers) must balance.

Route 1 — neutron bombardment in a reactor. Inside a research reactor such as ANSTO's OPAL, free neutrons are plentiful. A stable target nucleus that absorbs a neutron becomes a heavier isotope of the same element, and the extra neutron usually makes it radioactive. For example, stable cobalt-59 absorbs a neutron to become the γ-emitting therapy isotope cobalt-60 used in Section 3F:

$^{59}_{27}\mathrm{Co} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{60}_{27}\mathrm{Co}$

and stable molybdenum-98 absorbs a neutron to become molybdenum-99, the parent of the workhorse imaging isotope technetium-99m (met below):

$^{98}_{42}\mathrm{Mo} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{99}_{42}\mathrm{Mo}$

Isotopes made this way are rich in neutrons and tend to decay by β^- emission.

Route 2 — high-energy collisions in an accelerator. A **cyclotron** accelerates charged particles — usually protons — to very high energies and fires them at a target. A collision can knock particles out of the target nuclei and create new, proton-rich isotopes that tend to decay by β^+ (positron) emission — exactly the isotopes needed for PET scanning. The most important example is fluorine-18, made by bombarding oxygen-18 with protons:

$^{18}_{8}\mathrm{O} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{18}_{9}\mathrm{F} + {}^{1}_{0}\mathrm{n}$

(Check: top numbers $18 + 1 = 18 + 1$ ✓; bottom numbers $8 + 1 = 9 + 0$ ✓.) Because fluorine-18's half-life is only about 110 minutes, it must be made close to the scanner that will use it, and many Australian PET services run their own cyclotron on site. Source: IAEA, LiveChart of Nuclides, retrieved 2026-08-18.

The two routes are complementary: reactors such as OPAL supply the neutron-rich isotopes used for imaging and therapy across the country, while cyclotrons supply the short-lived positron emitters that PET scanning needs. Source: ANSTO, Medical radioisotopes, ansto.gov.au, retrieved 2026-08-18.

Ionising and non-ionising radiation. Section 3E defined **ionising radiation**: radiation carrying enough energy to knock electrons out of the atoms it passes through, leaving charged ions. Whether radiation is ionising depends on the energy carried by each photon or particle, and the electromagnetic spectrum (Section 1B) shows a clear pattern:

- **Non-ionising radiation** — radio waves, microwaves, infrared, visible light and lower-energy ultraviolet — has photons that can shake atoms and molecules but cannot eject their electrons.
- **Ionising radiation** — higher-energy ultraviolet, X-rays and γ rays — has photons energetic enough to ionise atoms. The α and β particles from radioactive decay are also ionising, because they are charged particles moving fast enough to strip electrons as they pass.

The two classes affect living tissue differently:

- **Ionising radiation** damages cells by the mechanism of Section 3E: ionisations break chemical bonds, the critical target is the cell's DNA, and the outcomes are repair, cell death, or a mutation that may lead to cancer years later. There is no completely safe dose; protection is a matter of keeping every dose as small as reasonably achievable and justifying any medical exposure by its benefit to the patient.
- **Non-ionising radiation** cannot break bonds by ionisation. Its main effect on tissue is **heating**: microwaves heat water-rich tissue, bright infrared and visible light warm the skin. At the low powers used in medical imaging the heating is tiny and controlled, but non-ionising does not mean harmless in all circumstances — intense non-ionising sources (industrial microwaves, lasers) can burn tissue or damage the eye by heating. The damage mechanism is thermal, not the DNA-breaking mechanism of ionising radiation.

	Ionising radiation	Non-ionising radiation
Examples	X-rays, γ rays, higher-energy ultraviolet; α and β particles	radio waves, microwaves, infrared, visible light, lower-energy ultraviolet
What it does to atoms	ejects electrons — ionisation	shakes atoms and molecules but does not eject electrons
Effect on living cells	breaks chemical bonds; DNA damage; cells killed or mutated (Section 3E)	mainly heating; at imaging powers the heating is tiny
Medical uses in this option	X-ray imaging, CT, SPECT, PET, radiotherapy	MRI

This distinction runs through every choice of imaging technique: X-ray, CT, SPECT and PET all use ionising radiation, so each scan is only performed when its expected benefit outweighs the small added long-term risk; MRI uses non-ionising radiation, so it delivers no ionising dose at all.

Medical imaging compared. The six techniques named in this option divide into two families by what their image shows:

- **Structural imaging** — X-ray photographs, CT and MRI — shows what the body's parts *look like*: their size, shape and position.
- **Functional imaging** — γ imaging, SPECT and PET — shows what the body's parts are *doing*: which tissues are collecting a tracer and how actively.

X-ray photograph. A narrow beam of hard X-rays passes through the body onto a detector on the far side. Bone, which is dense and contains heavier atoms, absorbs far more of the beam than soft tissue, so the detector records a two-dimensional shadow image: bright bone, darker soft tissue, black air. A chest X-ray is the familiar example; its effective dose is about $0.02\,\mathrm{mSv}$ — small compared with a year of natural background radiation ($1.5\,\mathrm{mSv}$ in Australia). Source: ARPANSA, Radiation dose comparison, retrieved 2026-08-18.

Computed tomography (CT). In a CT scanner the X-ray tube and its detectors rotate around the lying patient, taking hundreds of X-ray measurements from different angles. A computer uses these projections to reconstruct a cross-sectional slice through the body, and a stack of slices can be built into a three-dimensional image. CT shows soft tissue far better than a single X-ray photograph, but the many projections add up to a much larger dose — about $10\,\mathrm{mSv}$ for an abdominal scan, hundreds of chest X-rays' worth. Source: ARPANSA, Radiation dose comparison, retrieved 2026-08-18.

γ imaging and SPECT. Here the radiation source is *inside* the patient. A radioisotope that emits γ rays (a **tracer**, introduced below) is injected, and a **gamma camera** held outside the body detects the photons escaping from the patient and forms a two-dimensional image of where the tracer has collected. In **single photon emission computed tomography** (SPECT) the gamma camera rotates around the patient, and a computer reconstructs a three-dimensional map of the tracer's distribution. The name refers to the fact that each detected photon comes from a single radioactive decay, one photon at a time.

Positron emission tomography (PET). PET uses a tracer built on a positron (β^+) emitter such as fluorine-18. Section 3B described what happens next: an emitted positron meets an electron in the patient's tissue and the two annihilate, their energy carried away by two γ rays travelling in opposite directions. The scanner is a ring of detectors around the patient; when two detectors on opposite sides register γ rays at the same instant, the computer knows the annihilation happened somewhere on the line between them. Millions of such paired detections build a three-dimensional map of where the tracer is concentrated. Because the tracer is usually a glucose-like molecule, the image shows which tissues are consuming energy most actively — the brain and heart at work, or a cancer growing out of control.

Magnetic resonance imaging (MRI). MRI uses no radioactive material and no ionising radiation. The patient lies inside a very strong magnetic field, which makes the hydrogen nuclei (single protons) in the body's water and fat line up. Short bursts of radio waves disturb this alignment; as the nuclei settle back, they re-emit radio signals that differ between tissues and between locations. A computer converts the signals into images with outstanding detail of soft tissue — the brain, muscles, ligaments and organs. Scans take much longer than CT, and the strong magnetic field means MRI cannot be used for patients with certain metal implants or devices.

Technique	Radiation involved	Where it comes from	Image shows	Ionising dose?
X-ray photograph	X-rays	tube outside the body	structure, 2D shadow (bone especially)	yes — small
CT	X-rays	tube rotating around the body	structure, slices and 3D	yes — larger
γ imaging / SPECT	γ rays	injected tracer (e.g. technetium-99 m)	function, 2D / 3D tracer map	yes
PET	γ rays from annihilation	injected positron-emitting tracer (e.g. fluorine-18)	function, 3D map of tissue activity	yes
MRI	radio waves in a strong magnetic field	hydrogen nuclei in the body re-emit	structure, excellent soft-tissue detail	no

Medical radioisotopes in imaging and diagnosis. The trick of nuclear medicine is the **tracer**: a radioisotope attached to a molecule the body already handles chemically. The body cannot tell the radioactive atoms from ordinary ones, so the molecule goes where its chemistry sends it — into bone, into the heart muscle, through the kidneys — and the radiation it emits reports back to a detector outside the body where it has gone and how fast it is being taken up. That is functional information no X-ray photograph can supply.

An isotope used for imaging must satisfy three conditions:

1. **It must emit γ radiation.** Only γ rays can escape the body to reach an external camera. α and β radiation is absorbed inside the patient — it would add dose without adding image — and α radiation is the most damaging radiation per gray of absorbed dose (Section 3E).
2. **Its half-life must be short — hours to a day or so.** Long enough to be prepared, injected and imaged; short enough that the patient's dose ends soon after the scan.

3. **It must attach to a useful molecule** and keep its chemistry while it decays.

Technetium-99m is the isotope that fits these conditions best and is the most widely used imaging radioisotope in the world. The “m” marks it as a higher-energy form of the nucleus: it decays by emitting a single γ ray (energy $140\,\text{keV}$, where keV is a small energy unit used for photons and particles) with a half-life of 6.0 hours. Technetium-99m is itself made from molybdenum-99 (half-life 66 hours), which is produced in reactors including ANSTO’s OPAL and shipped to hospitals in a **generator** — a device from which the technetium-99m is washed out (“milked”) as needed over the following week. Attached to different carrier molecules, technetium-99m images bone, heart muscle, kidneys, lungs and more. Source: IAEA, LiveChart of Nuclides, retrieved 2026-08-18; ANSTO, Medical radioisotopes, ansto.gov.au, retrieved 2026-08-18.

Fluorine-18 plays the same role for PET. Attached to a glucose-like molecule, it reveals tissues consuming glucose rapidly — the standard way of finding many cancers and checking whether they have spread. Its half-life is about 110 minutes. Source: IAEA, LiveChart of Nuclides, retrieved 2026-08-18.

Diagnosis means reading these images: a region of heart muscle that takes up no tracer during exercise is not receiving blood; a kidney that collects tracer but never drains it is blocked; a bright spot on a bone scan can reveal where a cancer has spread. Contrast the whole enterprise with Section 3F, where the isotopes emit α or β radiation *because* the goal is to damage tissue. In imaging, the isotope is chosen to do as little damage as possible while reporting as much as possible.

Detection and penetration: matching the radiation to the job. Section 3B established the penetrating properties of the three nuclear radiations; Section 3E added how they are detected and how they damage tissue. Pulling those threads together explains why each medical application uses the radiation it does:

- **α particles** are stopped by the dead outer layer of skin or a few cells of living tissue, and they ionise more densely than any other common radiation. They are useless for imaging — none could escape the body to a detector — but inside the body, placed against diseased cells, their dense, short-range dose is a precision weapon: radium-223 in bone therapy (Section 3F). Detecting α radiation requires a detector with a very thin window, because so little material stops it.
- **β particles** travel a few millimetres in tissue. Like α, they cannot escape the body to form an image, but their slightly longer range suits internal therapy where the dose must cover a small volume: iodine-131 in the thyroid, lutetium-177 attached to tumour-seeking molecules (Section 3F).
- **γ rays** pass through the body. That one property makes them the radiation of medicine: escaping from an internal tracer they carry functional images out to a gamma camera (SPECT); aimed from outside as crossing beams they deliver therapy to deep tumours (Section 3F); and from a powerful cobalt-60 source they sterilise sealed medical equipment — syringes, gloves, dressings — because the penetrating rays kill micro-organisms right through the packaging, at doses around $25\,000\,\text{Gy}$ that would be instantly lethal to any person. Source: IAEA, Radiation Sterilization of Medical Devices, retrieved 2026-08-18. Detecting γ rays needs dense detector materials — such as scintillation crystals that flash with light when a γ ray is absorbed — because γ rays pass through so much matter without interacting.

Radiation	Penetration in the body	Can it escape to an outside detector?	Medical roles
α	stopped by dead skin; a few cells in living tissue	no	targeted internal therapy (radium-223)
β	a few millimetres	no	internal therapy (iodine-131, lutetium-177)
γ	through the whole body	yes	imaging (SPECT), external-beam therapy, sterilisation of equipment

The pattern is the whole section in one sentence: **imaging needs radiation that gets out of the body; therapy needs radiation that stops where the disease is.** Choosing between the two is an exercise in the penetrating and ionising properties of Section 3B and Section 3E — and, in this option, that choice is always weighed against the dose, the cost and who has access to the technology. That weighing is the work of the Option task below.

Worked examples

Example 1 — scaffolded

In a hospital X-ray tube, electrons are accelerated from rest through a potential difference of $100\,\text{kV}$ before striking the tungsten target. (a) Calculate the kinetic energy gained by each electron. (b) State the maximum energy that an X-ray photon produced by one of these electrons could carry, and justify your answer. (c) Only about $1\,\%$ of each electron's energy emerges as X-rays. Calculate the energy converted to thermal energy in the target by one electron, and comment on the result.

Take $e = 1.60 \times 10^{-19}\,\text{C}$ (Section 5A).

Working	Comment
$V = 100\,\text{kV} = 1.0 \times 10^{5}\,\text{V}$; $q = 1.60 \times 10^{-19}\,\text{C}$.	List the data.
(a) $E = q\,V = 1.60 \times 10^{-19} \times 1.0 \times 10^{5}$.	The energy gained by a charge accelerated through a potential difference (Section 5A).
$= 1.6 \times 10^{-14}\,\text{J}$.	Two significant figures.
(b) Maximum photon energy $= 1.6 \times 10^{-14}\,\text{J}$.	A photon cannot carry more energy than the kinetic energy of the electron that made it; the maximum occurs when one electron loses all its energy in a single deceleration.
(c) Thermal energy $= 99\,\%$ of $1.6 \times 10^{-14} = 0.99 \times 1.6 \times 10^{-14}$.	About $1\,\%$ emerges as X-rays, so the rest heats the target.
$\approx 1.6 \times 10^{-14}\,\text{J}$.	To two significant figures this rounds to the same value: essentially all of the electron's energy heats the target.

The comment in (c) is why X-ray targets are made of high-melting-point metal, spun and cooled — the tube is, energetically, a heater that happens to leak X-rays.

Example 2 — scaffolded

Medical radioisotopes are made by bombarding stable target nuclei. Complete each production equation, identifying the missing nucleus or particle, and check that mass number and charge are conserved (Section 3B).

(a) Neutron bombardment of molybdenum-98, the first step in making the parent of technetium-99m:

$^{98}_{42}\text{Mo} + {}^{1}_{0}\text{n} \rightarrow ?$

(b) Bombardment of oxygen-18 with protons in a cyclotron, the production route for the PET isotope fluorine-18:

$^{18}_{8}\text{O} + {}^{1}_{1}\text{H} \rightarrow ? + {}^{1}_{0}\text{n}$

Working	Comment
(a) Let the product be $^{A}_{Z}X$. Top numbers: $98 + 1 = A$, so $A = 99$.	Mass number is conserved.
Bottom numbers: $42 + 0 = Z$, so $Z = 42$.	Charge is conserved; absorbing a neutron does not change the proton count.
$Z = 42$ is molybdenum: $^{98}_{42}\text{Mo} + {}^{1}_{0}\text{n} \rightarrow {}^{99}_{42}\text{Mo}$.	The product is a heavier isotope of the same element, molybdenum-99.
(b) Let the missing nucleus be $^{A}_{Z}X$. Top numbers: $18 + 1 = A + 1$, so $A = 18$.	Mass number is conserved.
Bottom numbers: $8 + 1 = Z + 0$, so $Z = 9$.	Charge is conserved.
$Z = 9$ is fluorine: $^{18}_{8}\text{O} + {}^{1}_{1}\text{H} \rightarrow {}^{18}_{9}\text{F} + {}^{1}_{0}\text{n}$.	The product is the PET isotope fluorine-18 — the decay of which was treated in Section 3B.

Example 3 — unscaffolded

ANSTO supplies molybdenum-99 ($t_{1/2} = 66$ h) to a hospital in a generator, from which the daughter isotope technetium-99m ($t_{1/2} = 6.0$ h) is washed out for scans as needed. A generator is prepared on Monday 06:00 and its technetium-99m is first used on Saturday 18:00, 132 hours later. (a) Calculate the fraction of the original molybdenum-99 remaining at that time. (b) A patient's dose of technetium-99m is drawn from the generator at Saturday 18:00 and injected 18 hours later. Calculate the fraction of the technetium-99m remaining at injection. (c) Explain why these two half-lives are well matched to their roles in the supply chain.

(a) 132 hours is $\frac{132}{66} = 2.0$ half-lives of molybdenum-99, so the fraction remaining is

$$\left(\frac{1}{2}\right)^2 = \frac{1}{4}.$$

(b) 18 hours is $\frac{18}{6.0} = 3.0$ half-lives of technetium-99m, so the fraction remaining is

$$\left(\frac{1}{2}\right)^3 = \frac{1}{8}.$$

(c) The molybdenum-99 half-life of 66 hours is long enough for the generator to survive manufacture, transport and about a week of daily use in the hospital, yet short enough that a spent generator soon decays to a small fraction of its original activity. The technetium-99m half-life of 6.0 hours is long enough to attach the isotope to its carrier molecule, inject the patient and complete the scan, yet short enough that almost all of it has decayed within a day or two, keeping the patient's dose brief. The parent–daughter pair works because one half-life suits the logistics and the other suits the patient.

Example 4 — unscaffolded

A patient needs detailed images of the soft tissue of the liver, repeated several times a year to monitor a condition. The radiology service can offer X-ray photographs, CT or MRI. Select the most suitable technique and justify the choice, and explain why each of the other two is less suitable for this patient.

MRI is the most suitable technique. It produces excellent detail of soft tissue such as the liver, and it uses no ionising radiation — radio waves and a strong magnetic field — so repeating the scan several times a year adds no cumulative ionising dose. For a patient who must be imaged again and again, avoiding that accumulated dose is decisive.

X-ray photographs are unsuitable for two reasons: a plain X-ray image shows soft tissue poorly (the liver would be barely distinguishable from its surroundings), and it uses ionising radiation, so it would fail on both image quality and dose.

CT is unsuitable even though it images the liver well: an abdominal CT delivers about $10\,\mathrm{mSv}$, hundreds of times the dose of a chest X-ray, and several CT scans per year would accumulate a substantial ionising dose. The small added long-term risk of each scan (Section 3E) is acceptable when a single scan answers an urgent question, but for repeated monitoring the non-ionising technique is preferred whenever it can answer the clinical question.

Practice questions

Question 1 *(scaffolded)* A dental X-ray unit accelerates electrons through a potential difference of $60\,\mathrm{kV}$. Take $e = 1.60 \times 10^{-19}\,\mathrm{C}$. (a) Calculate the kinetic energy gained by each electron. (b) State the maximum energy that an X-ray photon from this unit could carry. (c) Explain why the X-rays used for imaging must be able to pass through the body, and state what happens, inside the patient's tissue, to the X-rays that do not pass through.

Question 2 *(scaffolded)* Complete each isotope-production equation, identifying the missing nucleus or particle. (a) Neutron bombardment of molybdenum-98 in a reactor: ${}^{98}_{42}\mathrm{Mo} + {}^{1}_{0}\mathrm{n} \rightarrow ?$ (b) Proton bombardment of tellurium-123 in a cyclotron, producing the thyroid-imaging isotope iodine-123: ${}^{123}_{52}\mathrm{Te} + {}^{1}_{1}\mathrm{H} \rightarrow {}^{123}_{53}\mathrm{I} + ?$ (c) State one difference between the kinds of medical radioisotope produced in reactors and in cyclotrons.

Question 3 *(scaffolded)* A dose of technetium-99m ($t_{1/2} = 6.0$ h) is prepared at 07:00 containing 2.4×10^{12} technetium-99m nuclei, and is injected into the patient at 19:00 the same day. (a) Calculate the elapsed time in units of the half-life. (b) Calculate the number of technetium-99m nuclei remaining at injection. (c) Explain why a half-life of 6.0 hours suits an isotope used for same-day imaging.

Question 4 *(scaffolded)* (a) Define ionising radiation. (b) Classify each of the following as ionising or non-ionising: X-rays; radio waves; γ rays; visible light. (c) Explain why a patient receives no ionising-radiation dose during an MRI scan.

Question 5 *(scaffolded)* An abdominal CT scan delivers an effective dose of about $10\,\text{mSv}$. The Australian average annual dose from natural background radiation is about $1.5\,\text{mSv}$. (a) Calculate the CT scan's dose as a multiple of the annual background dose. (b) Explain what is meant by the "small added long-term risk" that accompanies such a dose (Section 3E). (c) Explain why a doctor might choose MRI rather than a repeat CT to monitor the same patient over several years.

Question 6 *(scaffolded)* Match each radiation — α, β, γ — to the medical application where its penetrating properties make it the right choice, and give the physical reason in each case. (a) A tracer detected by a camera outside the patient's body. (b) A radioisotope swallowed and absorbed by the thyroid gland, to destroy overactive tissue. (c) Sterilising sealed packs of syringes.

Question 7 Distinguish between soft X-rays and hard X-rays, and explain why the beam used for medical imaging is filtered to remove the soft component before it reaches the patient.

Question 8 Describe the two processes by which the electrons striking the target of an X-ray tube produce X-ray photons, stating how the photon energies differ between the two processes.

Question 9 A regional hospital has installed a cyclotron to serve its PET scanner. Explain how the cyclotron produces medical radioisotopes, and explain why the hospital still depends on reactor-produced isotopes such as technetium-99m for its other nuclear-medicine scans.

Question 10 Fluorine-18 has a half-life of 110 minutes. A PET tracer is synthesised at 08:00 and injected into the patient at 11:40. Calculate the fraction of the fluorine-18 remaining at injection, and explain why PET services need either an on-site cyclotron or very fast transport arrangements.

Question 11 Compare a plain X-ray photograph and a SPECT image of the same part of the body. In your answer, refer to where the radiation detected in each image comes from, and to what each image shows (structure or function).

Question 12 Describe how a PET scan locates the regions of the body where a fluorine-18 tracer has concentrated. Your answer should refer to what happens to the emitted positrons and to how the scanner's detectors use the products.

Question 13 A young patient needs imaging of the same region of the brain several times over a number of years to monitor treatment. Explain why MRI is preferred to CT for the repeated scans, referring to the radiation involved in each technique and to what repeated exposure implies.

Question 14 A molybdenum-99 generator ($t_{1/2} = 66$ h) is prepared for a hospital. Calculate the fraction of the molybdenum-99 remaining after 264 hours, and use your answer to explain why hospitals replace generators roughly weekly rather than keeping them indefinitely.

Question 15 Explain why radioisotopes used for imaging are chosen to be γ emitters with half-lives of hours to a day, and explain why an α-emitting isotope would be unsuitable for imaging even though α radiation is easy to detect with the right instrument.

Question 16 A social media post claims: "MRI scans expose your brain to harmful radiation, just like X-rays." Critically evaluate this claim using the physics of the two imaging techniques.

Question 17 A chest X-ray delivers an effective dose of about $0.02\,\text{mSv}$. In one year a patient has 15 chest X-rays. Calculate the patient's total effective dose from these X-rays, and compare it with the Australian average annual dose from natural background radiation ($1.5\,\text{mSv}$).

Question 18 A student proposes: “Medical imaging that uses ionising radiation should be replaced entirely by MRI wherever it is technically possible.” Evaluate this proposal. Present the strongest case for it and the strongest case against it before reaching a conclusion.

Answers

Question 1 (a) 9.6×10^{-15} J; (b) 9.6×10^{-15} J; (c) see solutions — X-rays that do not pass through are absorbed in the tissue, contributing to the patient's dose. **Question 2** (a) $^{99}_{42}Mo$; (b) $^{1}_{0}n$; (c) reactor isotopes are neutron-rich and tend to decay by β^- emission; cyclotron isotopes are proton-rich and tend to decay by β^+ emission. **Question 3** (a) 2.0 half-lives; (b) 6.0×10^{11} nuclei; (c) see solutions. **Question 4** (a) radiation carrying enough energy to knock electrons out of the atoms it passes through; (b) ionising: X-rays, γ rays; non-ionising: radio waves, visible light; (c) MRI uses radio waves and a magnetic field — non-ionising. **Question 5** (a) about 6.7; (b) a small increase in the probability of developing cancer years later; (c) MRI uses no ionising radiation, so repeated scans add no cumulative ionising dose. **Question 6** (a) γ — only γ escapes the body; (b) β — short range deposits the dose in the thyroid tissue that absorbed it; (c) γ — penetrating rays kill micro-organisms through the packaging. **Question 7** See worked solution — soft X-rays are lower-energy and less penetrating; they would be absorbed in the patient, adding dose without contributing to the image. **Question 8** See worked solution — deceleration gives a continuous range of energies; inner-shell electron transitions give photons of definite energies. **Question 9** See worked solution — cyclotrons make proton-rich positron emitters by high-energy collisions; reactor isotopes such as technetium-99m come from neutron bombardment and cannot be made in a cyclotron. **Question 10** $\frac{1}{4}$; see solutions for the logistics explanation. **Question 11** See worked solution — X-ray: external beam, structure; SPECT: internal tracer, function. **Question 12** See worked solution — positron annihilation into two opposite γ rays; ring of detectors registers coincidences. **Question 13** See worked solution — MRI uses non-ionising radiation; CT scans would accumulate ionising dose with each repeat. **Question 14** $\frac{1}{16}$; a generator this old produces too little technetium-99m for practical scans. **Question 15** See worked solution — γ escapes the body to the detector; α cannot escape and deposits a densely damaging dose in the patient. **Question 16** See worked solution — the claim is false: MRI uses non-ionising radiation, X-rays are ionising. **Question 17** 0.30 mSv; one-fifth of the annual background dose. **Question 18** See worked solution — replacement is not possible or sensible in all cases; evaluation weighs dose against image quality, availability and cost.

Fully-worked solutions

Question 1 $V=60\,\text{kV}=6.0\times10^{4}\,\text{V}$; $q=e=1.60\times10^{-19}\,\text{C}$. (a) $E=qV=1.60\times10^{-19}\times6.0\times10^{4}=9.6\times10^{-15}\,\text{J}$. (b) The maximum photon energy equals the electron's kinetic energy, 9.6×10^{-15} J: a single photon cannot carry more energy than the electron that created it. (c) To form an image, the X-rays must pass through the body and reach the detector on the far side; the pattern of what gets through and what does not *is* the image. The X-rays that do not pass through are absorbed in the patient's tissue, where their energy is deposited — that absorption is what gives the patient their dose, so it is kept as small as the diagnostic purpose allows.

Question 2 (a) Top numbers: $98+1=99$. Bottom numbers: $42+0=42$. The product is $^{99}_{42}Mo$, molybdenum-99 — the parent isotope of technetium-99m. (b) Top numbers: $123+1=123+A$, so $A=1$. Bottom numbers: $52+1=53+Z$, so $Z=0$. The missing particle is $^{1}_{0}n$, a neutron. (c) Reactors produce isotopes by neutron bombardment; the products are neutron-rich and tend to decay by β^- emission (some, like molybdenum-99, going on to supply γ-emitting imaging isotopes). Cyclotrons produce isotopes by high-energy collisions of charged particles; the products are proton-rich and tend to decay by β^+ emission — the positron emitters used in PET.

Question 3 $t_{1/2}=6.0$ h. (a) Elapsed time $=19:00-07:00=12$ h. Number of half-lives $=\frac{12}{6.0}=2.0$. (b) Fraction remaining $=\left(\frac{1}{2}\right)^2=\frac{1}{4}$, so nuclei remaining $=\frac{2.4\times10^{12}}{4}=6.0\times10^{11}$. (c) Six hours is long enough for the isotope to be prepared, attached to its carrier molecule, injected and imaged, yet short enough that within a day or two almost all of it has decayed, so the patient's dose is brief. An isotope with a half-life of minutes would decay before the scan; one with a half-life of months would keep irradiating the patient long after the image was taken.

Question 4 (a) Ionising radiation is radiation carrying enough energy to knock electrons out of the atoms it passes through, leaving charged ions (Section 3E). (b) Ionising: X-rays and γ rays (their photons are energetic enough to eject electrons). Non-ionising: radio waves and visible light (their photons can excite atoms but cannot eject electrons). (c)

An MRI scan uses a strong magnetic field and radio waves. Radio waves are non-ionising — their photons cannot eject electrons from atoms — so there is no ionisation of the patient's tissue and no ionising-radiation dose.

Question 5 (a) Multiple $=\dfrac{10}{1.5}=6.7$: one abdominal CT delivers about seven times the dose Australians receive from natural background radiation in a whole year. (b) Low doses of ionising radiation do not cause immediate illness; they leave a small number of damaged cells whose DNA has been altered. The long-term effect is a small increase in the *probability* of developing cancer years or decades later — the probability, not the severity, increases with dose, and no dose below which this added risk is exactly zero has been demonstrated (Section 3E). (c) MRI uses non-ionising radiation (radio waves and a magnetic field), so each MRI scan adds no ionising dose at all. Repeated CT scans, each about $10\,\text{mSv}$, would accumulate a substantial ionising dose over the years and with it a growing added long-term risk; MRI avoids that accumulation provided it can answer the clinical question.

Question 6 (a) **γ radiation.** A tracer inside the patient can only be detected from outside if its radiation escapes the body. α particles are stopped within a few cells and β particles within a few millimetres of tissue; only γ rays penetrate right through the body to the camera. (b) **β radiation.** Once the swallowed isotope is absorbed by the thyroid, its β particles travel only a few millimetres, so their dose is deposited almost entirely in the thyroid tissue that collected the isotope, destroying the overactive cells while largely sparing tissue beyond. (This is the iodine-131 therapy of Section 3F.) (c) **γ radiation.** Sterilisation requires radiation that reaches every surface of the sealed pack, killing micro-organisms through the packaging without opening it; only γ rays from a strong source such as cobalt-60 are penetrating enough.

Question 7 Model answer (4 marks: 1 mark for the soft/hard distinction in energy, 1 mark for the penetration difference, 1 mark for what soft X-rays would do to the patient, 1 mark for the purpose of the filter). Soft X-rays have lower photon energies (lower frequencies, longer wavelengths) than hard X-rays, and are correspondingly less penetrating: they are absorbed within a short distance of the body's surface. Hard X-rays have higher photon energies and penetrate far enough to pass through the body to the detector. Since the image is formed only by the X-rays that get through, the soft component of the beam contributes nothing to the image — it is absorbed in the patient and adds dose. The filter removes this useless soft component before the beam reaches the patient, reducing the dose without weakening the imaging part of the beam.

Question 8 Model answer (4 marks: 1 mark for each process and 1 mark for each energy character). In the **deceleration process**, an incoming electron is deflected and slowed as it passes near a target nucleus; the kinetic energy it loses is emitted as an X-ray photon. Different electrons lose different amounts of energy, so this process produces a continuous range of photon energies, up to a maximum equal to the full kinetic energy of the incoming electrons. In the **inner-shell process**, an incoming electron knocks an inner-shell electron out of a target atom; when an outer-shell electron drops down to fill the vacancy, it emits an X-ray photon of a definite energy characteristic of the target metal. The first process gives a continuous spread of energies; the second gives sharp, definite energies.

Question 9 Model answer (4 marks: 1 mark for the cyclotron mechanism, 1 mark for the type of isotope it makes, 1 mark for the reactor route, 1 mark for why both are needed). A cyclotron accelerates charged particles — usually protons — to high energies and fires them at a target; the high-energy collisions transform the target nuclei into new isotopes. The products are proton-rich and decay by β^+ emission — the positron emitters (such as fluorine-18) that PET scanning needs. Reactor-produced isotopes such as technetium-99m are made the other way, by neutron bombardment of target nuclei, and the neutron-rich products decay by β^- emission (molybdenum-99 decaying to technetium-99m). A cyclotron cannot supply these neutron-rich isotopes, and its own products' half-lives are often too short to ship far — so the hospital's SPECT and general nuclear-medicine work still depends on reactor-produced isotopes supplied from facilities such as ANSTO's OPAL reactor.

Question 10 $t_{1/2}=110$ min. Elapsed time $=08:00$ to $11:40=220$ min $=\dfrac{220}{110}=2.0$ half-lives, so the fraction remaining is

$$\left(\frac{1}{2}\right)^2=\frac{1}{4}.$$

By the time of injection three-quarters of the fluorine-18 has already decayed. Because the half-life is so short, the usable amount falls away within hours of production: PET services therefore need the cyclotron on site or a very fast supply chain, otherwise the tracer would decay before it reached the patient — a supply problem technetium-99m, with its 6.0-hour half-life and its 66-hour parent, is far more forgiving of.

Question 11 Model answer (4 marks: 1 mark for each source of radiation and 1 mark for each type of information). In a plain X-ray photograph the radiation comes from a tube *outside* the body: a beam of X-rays passes through the patient and the detector records the pattern of what gets through, producing a shadow image of the body's **structure** — bone clearly, soft tissue poorly. In a SPECT image the radiation comes from *inside* the body: a γ-emitting tracer has been injected, collects in the tissues its chemistry sends it to, and the escaping γ rays are recorded by a rotating gamma camera that reconstructs a three-dimensional map. The SPECT image therefore shows **function** — where the tracer went and how actively the tissue took it up — rather than just what the tissue looks like.

Question 12 Model answer (4 marks: 1 mark for the positron's annihilation, 1 mark for the two opposite γ rays, 1 mark for coincidence detection by the ring, 1 mark for building the map). The fluorine-18 in the tracer decays by β^+ emission. Each emitted positron travels a very short distance in the tissue before meeting an electron; the two annihilate and their energy is carried away as two γ rays travelling in opposite directions (Section 3B). The scanner is a ring of detectors around the patient; when two detectors on opposite sides of the ring register γ rays at the same instant, the scanner knows the annihilation occurred somewhere on the straight line joining those two detectors. Recording millions of such coincidences from all directions lets the computer reconstruct a three-dimensional map of where the tracer — and hence the glucose-consuming tissue — is concentrated.

Question 13 Model answer (3 marks: 1 mark for the radiation each technique uses, 1 mark for the cumulative-dose point, 1 mark for the conclusion). CT uses X-rays — ionising radiation — and each scan adds its dose (about $10\,\mathrm{mSv}$ for an abdominal scan, of similar order for the head and body regions scanned repeatedly) to the patient's lifetime total, and with it a small added long-term risk of cancer (Section 3E). MRI uses radio waves in a strong magnetic field — non-ionising radiation — and contributes no ionising dose at all. For repeated scans over years, the ionising doses of repeated CT would accumulate while MRI's would not, so MRI is preferred whenever it can answer the clinical question — as it usually can for brain imaging, where its soft-tissue detail is outstanding.

Question 14 $t_{1/2}=66$ h. 264 hours is $\frac{264}{66}=4.0$ half-lives, so the fraction remaining is

$$\left(\frac{1}{2}\right)^4=\frac{1}{16}.$$

After four half-lives the generator holds only one-sixteenth of its original molybdenum-99, so it can produce only a small fraction of the technetium-99m it could when new: scans would take longer, doses would be weaker, and eventually there is too little molybdenum-99 to make useful amounts of technetium-99m at all. Hospitals therefore replace generators roughly weekly — on that schedule the molybdenum-99 has decayed to between one-quarter and one-eighth of its original amount, still enough for daily imaging.

Question 15 Model answer (4 marks: 1 mark for γ escaping the body, 1 mark for why α cannot image, 1 mark for the half-life argument, 1 mark for the dose point). An imaging isotope must be detected from outside the body, so its radiation must escape the body to reach the camera. γ rays penetrate the whole body and get out; α particles are stopped by a few cells of tissue and could never reach an external detector, whatever the instrument used outside. Nor is α radiation harmless inside: it ionises densely, with a radiation weighting factor of 20 (Section 3E), so an internal α emitter would deliver a large, damaging equivalent dose to the patient for no imaging benefit. The half-life must be long enough — hours to a day — for the isotope to be prepared, attached to its carrier molecule, injected and imaged, yet short enough that the patient's dose ends soon after the scan; a long-lived isotope would keep irradiating the patient for months.

Question 16 Model answer (4 marks: 1 mark for identifying the claim as false, 1 mark for what X-rays are, 1 mark for what MRI uses, 1 mark for the ionising/non-ionising distinction). The claim is false, and the error is a confusion between ionising and non-ionising radiation. X-rays are ionising electromagnetic radiation: their photons are energetic enough to knock electrons out of atoms, and it is this ionisation that can damage DNA and carries the small long-term risk associated with X-ray imaging. MRI uses no X-rays and no radioactive material: the patient is placed in a strong magnetic field and exposed to radio waves, which are non-ionising — their photons cannot eject electrons from atoms. At the powers used in scanning, the known effect of the radio waves is slight heating, not ionisation damage. So while any medical procedure should be used only when its benefit justifies it, the statement that MRI exposes the brain to radiation “just like X-rays” is wrong in physics: the two techniques use fundamentally different kinds of radiation, and only one of them is ionising.

Question 17 Dose per X-ray $= 0.02\,\text{mSv}$. Total dose $= 15 \times 0.02 = 0.30\,\text{mSv}$. Comparison with background: $\frac{0.30}{1.5} = 0.20$ — the fifteen X-rays together deliver one-fifth of the dose every Australian receives from natural background radiation in an average year. The comparison puts the medical dose in perspective: real, worth recording, but small next to the background exposure everyone receives whether they visit a hospital or not.

Question 18 A good evaluation hears the proposal at full strength before answering it.

The case for the proposal: it rests on a true and important physics fact. X-ray, CT, SPECT and PET all use ionising radiation, whose long-term risk — a small added probability of cancer years later — grows with accumulated dose (Section 3E). MRI uses non-ionising radiation and delivers no such dose. Replacing ionising techniques with MRI wherever possible would therefore reduce patients' lifetime doses, which is exactly what radiation protection asks for.

The case against the proposal: it ignores what each technique can and cannot do. MRI shows soft tissue superbly but is not a drop-in replacement for everything: plain X-rays remain the fast, cheap, low-dose way to image bone and the chest; functional imaging with tracers (SPECT and PET) reveals what tissue is *doing* — blood flow, glucose consumption — information MRI generally cannot supply in the same way; PET scanning detects annihilation photons from inside the body and has no MRI equivalent for whole-body cancer staging. MRI is also slower (a problem for emergencies and for patients who cannot hold still), more expensive, and unsafe for patients with certain metal implants — so “wherever technically possible” covers fewer cases than the proposal suggests.

Conclusion: the proposal names the right goal — keep every ionising dose justified and as small as possible — but states it too absolutely. Ionising-radiation imaging should be replaced by MRI *where MRI can answer the clinical question*, and often it can; but X-ray, CT, SPECT and PET each remain the best tool for some jobs, and the justified small dose they deliver is the price of information no other technique provides. The physics supports selective replacement guided by benefit versus risk, not a blanket ban.

Option task — Unit 2 Outcome 2 (house convention)

> **Status.** The study design fixes no mark allocations for Units 1 & 2; assessment of outcomes is school-based. This task and its 30 marks are **house convention** (TOC §2.2, §7.3), not a VCAA requirement. It closes the option and assesses the Communicating physics dot points (U2.2.CP.1–.5), which are taught in Sections 10A and 10B.

Format. A **physics-referenced response to an issue** — one of the assessment task types listed in the study design for Unit 2 Outcome 2 (*VCE Physics Study Design, Unit 2, Area of Study 2*). Length: 800–1200 words, or an equivalent presentation with notes.

Choose one of the following issues. Each is drawn from the contexts the study design lists for this option.

1. **Access and equity.** Advanced medical imaging such as PET and MRI is concentrated in the major cities and larger centres; patients outside those centres must travel — sometimes hundreds of kilometres — or wait longer for scans. *Evaluate whether the Victorian Government should fund additional PET scanners and MRI machines in large regional towns.* You will need to research and collate secondary data (for example, the distribution of scanners, travel distances, the cost of the machines and of travel, and the doses and benefits involved).
2. **Risk and benefit.** A media report claims that “routine CT scans are needlessly exposing Australians to dangerous levels of radiation”. *Critically evaluate this claim*, using the physics of X-ray production and imaging, the dose figures studied in this section and in Section 3E, and the principles of justification and keeping doses small.
3. **Technology choice.** A sports-medicine clinic that treats mostly joint and soft-tissue injuries is deciding whether to install a new CT scanner or a new MRI machine. *Advise the clinic which machine to buy*, with reference to the physics of each imaging technique and the needs of the clinic's patients.

Requirements. Your response must:

- evaluate the validity of at least three sources of information and use only sources that survive that evaluation (U2.2.CP.1);
- define the key physics terms you use — for example, ionising radiation, tracer, half-life — and use correct terminology, units and representations throughout (U2.2.CP.2);
- include at least one data representation (a table or graph — for example, comparing doses, costs or access) and discuss the limitations of the models and explanations you rely on (U2.2.CP.3);
- discuss at least two sociocultural, economic, legal or political factors relevant to the issue (U2.2.CP.4);
- state a clear stance, opinion or solution and justify it with physics (U2.2.CP.5).

Record your sources and your evaluation of them in your logbook (Section 14F).

Marking rubric (30 marks).

Criterion (Communicating physics dot point)	Marks	5–6 marks	3–4 marks	1–2 marks
1. Validity of sources (CP.1)	6	Three or more sources evaluated with explicit validity criteria (authority, currency, independence); only valid sources used.	Sources evaluated but criteria are thin, or one weak source is used uncritically.	Sources listed without evaluation, or evaluation is asserted, not argued.
2. Physics concepts and terminology (CP.2)	6	Key terms defined at first use; terminology, units and representations correct and consistent throughout.	Mostly correct; a definition missing or a misuse of terminology that does not undermine the argument.	Frequent errors or undefined terms that obscure the physics.
3. Data representations, models and their limitations (CP.3)	6	At least one correct, well-labelled representation; limitations of the explanations and models used are identified and discussed.	A representation present but thin, or limitations noted without discussion.	No representation, or limitations ignored.
4. Societal factors (CP.4)	6	At least two sociocultural, economic, legal or political factors identified and genuinely woven into the argument.	Two factors named but treated superficially.	One factor, or factors listed without connection to the issue.
5. Stance justified by physics (CP.5)	6	A clear stance whose justification is explicitly physical (dose, penetration, image quality, cost of the physics) and consistent with the evidence presented.	A stance stated with some physics justification, but parts rest on assertion.	A stance asserted, or a conclusion not supported by the physics presented.

Marking note. Marks are awarded for the quality of the reasoning, not for the conclusion reached. Two students taking opposite stances on the same issue can both receive full marks if both define their terms, evaluate their sources, present their evidence honestly and reason from physics to their conclusion. A response that reaches the “expected” stance by weak reasoning does not outscore a well-reasoned response that reaches the opposite stance.