
SL Paper 2

This question is about thermal properties of matter.

a. Explain, in terms of the energy of its molecules, why the temperature of a pure substance does not change during melting. [3]

b. Three ice cubes at a temperature of 0°C are dropped into a container of water at a temperature of 22°C . The mass of each ice cube is 25 g and the mass of the water is 330 g. The ice melts, so that the temperature of the water decreases. The thermal capacity of the container is negligible. [4]

The following data are available.

$$\text{Specific latent heat of fusion of ice} = 3.3 \times 10^5 \text{ J kg}^{-1}$$

$$\text{Specific heat capacity of water} = 4.2 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$$

Calculate the final temperature of the water when all of the ice has melted. Assume that no thermal energy is exchanged between the water and the surroundings.

Markscheme

a. energy supplied/bonds broken/heat absorbed;

increases potential energy;

no change in kinetic energy (so no change in temperature);

b. use of $M \times 4.2 \times 10^3 \times \Delta\theta$

$$ml = 75 \times 10^{-3} \times 3.3 \times 10^5 / 24750 \text{ J};$$

recognition that melted ice warms and water cools to common final temperature;

3.4°C ;

Examiners report

a. [N/A]

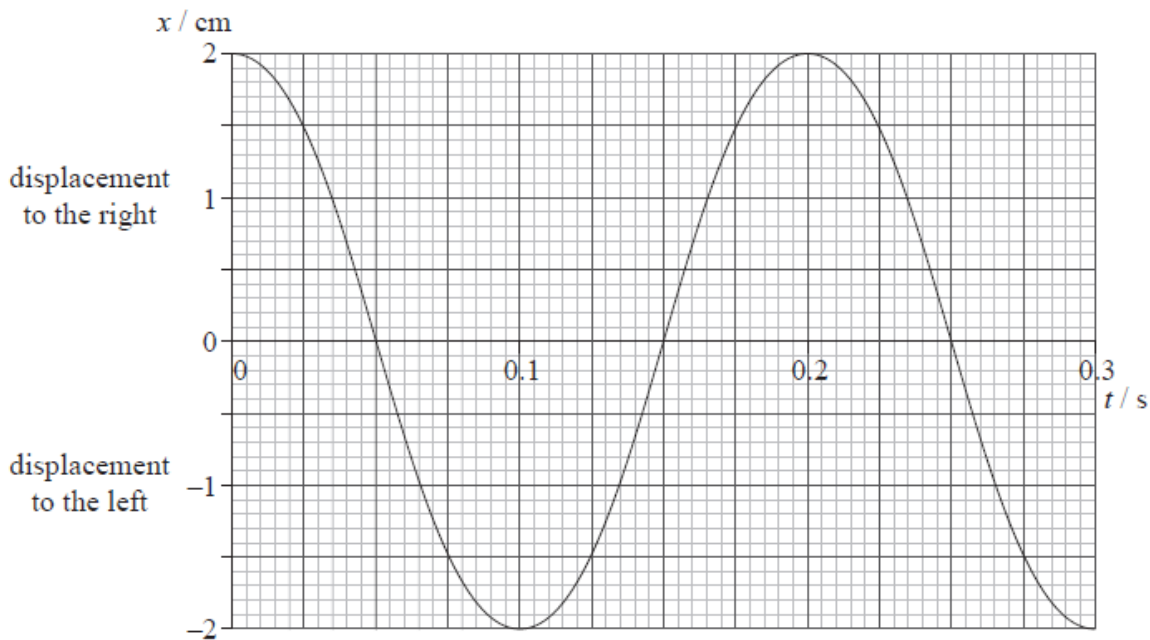
b. [N/A]

Part 2 Simple harmonic oscillations

A longitudinal wave travels through a medium from left to right.

Graph 1 shows the variation with time t of the displacement x of a particle P in the medium.

Graph 1



a. For particle P,

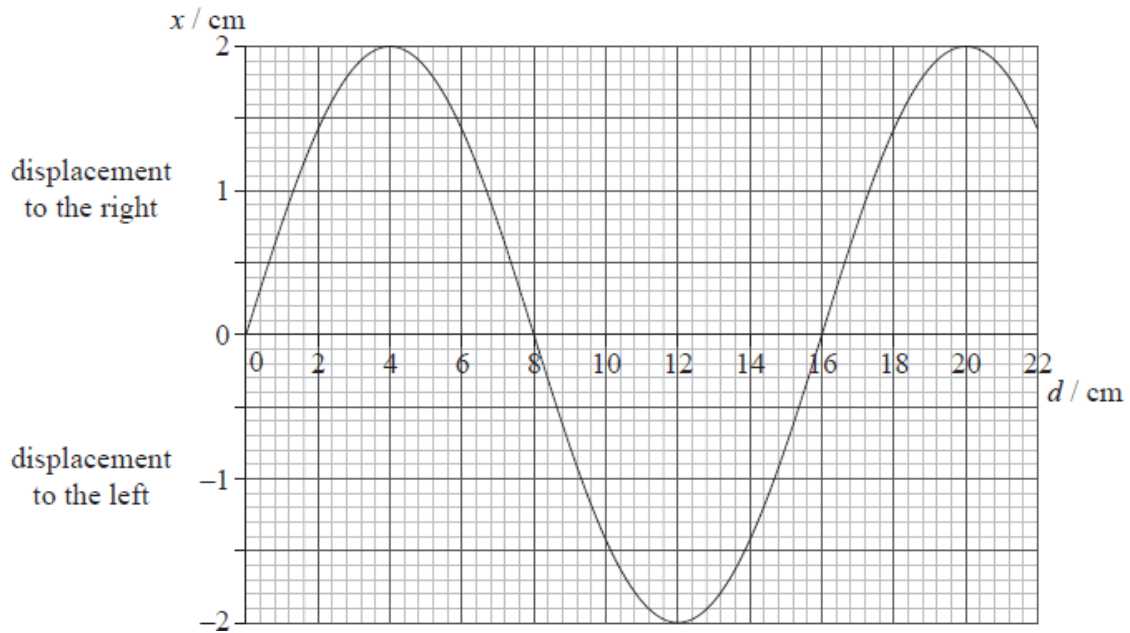
[6]

- (i) state how graph 1 shows that its oscillations are not damped.
- (ii) calculate the magnitude of its maximum acceleration.
- (iii) calculate its speed at $t=0.12$ s.
- (iv) state its direction of motion at $t=0.12$ s.

b. Graph 2 shows the variation with position d of the displacement x of particles in the medium at a particular instant of time.

[4]

Graph 2

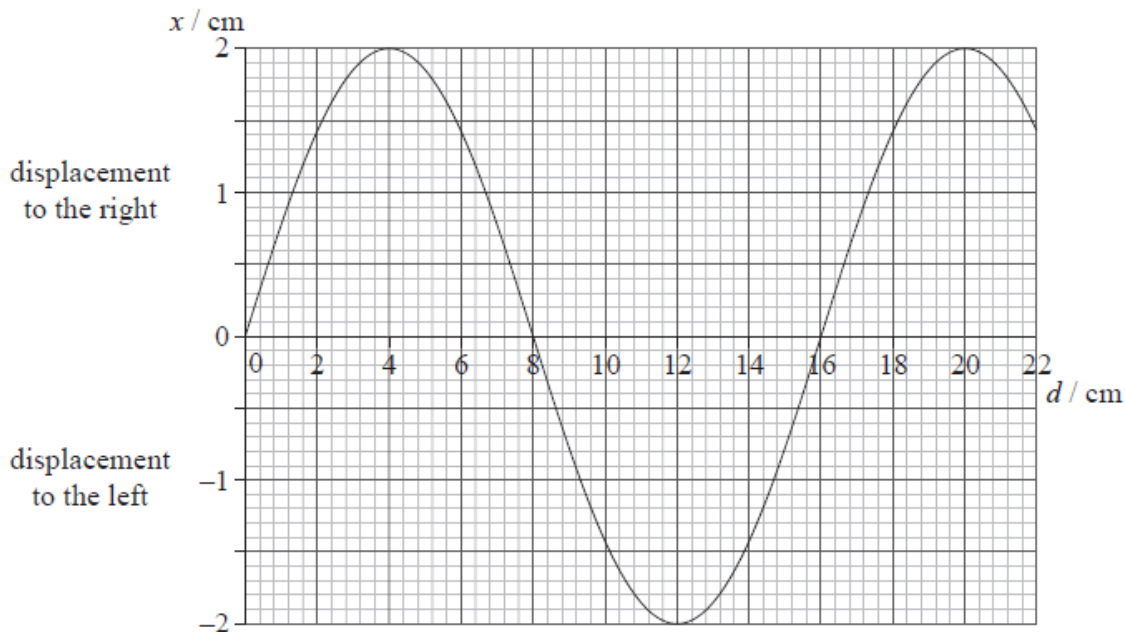


Determine for the longitudinal wave, using graph 1 and graph 2,

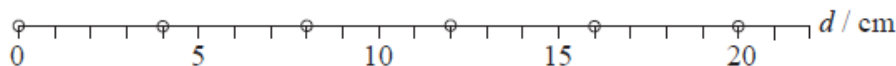
- (i) the frequency.
- (ii) the speed.

c. **Graph 2** – reproduced to assist with answering (c)(i).

[4]



(c) The diagram shows the equilibrium positions of six particles in the medium.



(i) On the diagram above, draw crosses to indicate the positions of these six particles at the instant of time when the displacement is given by graph 2.

(ii) On the diagram above, label with the letter C a particle that is at the centre of a compression.

Markscheme

a. (i) the amplitude is constant;

(ii) period is 0.20s;

$$a_{\max} = \left(\left[\frac{2\pi}{T} \right]^2 x_0 = 31.4^2 \times 2.0 \times 10^{-2} \right) = 19.7 \approx 20 \text{ms}^{-2}$$

Award [2] for correct bald answer and ignore any negative signs in answer.

(iii) displacement at $t = 0.12\text{cm}$ is $(-)1.62\text{cm}$;

$$v \left(= \frac{2\pi}{T} \sqrt{x_0 - x^2} \right) = 31.4 \sqrt{(2.0 \times 10^{-2})^2 - (1.62 \times 10^{-2})^2} = 0.37 \text{ms}^{-1};$$

Accept displacement in range 1.60 to 1.70 cm for an answer in range 0.33ms⁻¹ to 0.38ms⁻¹.

or

$$v_0 = \frac{2\pi}{T} x_0 = 0.628 \text{ms}^{-1};$$

$$|v| = \left(\left| -v_0 \sin \left[\frac{2\pi}{T} t \right] \right| \Rightarrow |v| = \left| -0.628 \sin [31.4 \times 0.12] \right| = \left| 0.37 \right| \right) = 0.37 \text{ms}^{-1};$$

or

drawing a tangent at 0.12s;

measurement of slope of tangent;

Accept answer in range 0.33ms⁻¹ to 0.38ms⁻¹.

b. (i) use of $f = \frac{1}{T}$;

$$\text{and so } f \left(= \frac{1}{0.20} \right) = 5.0 \text{Hz};$$

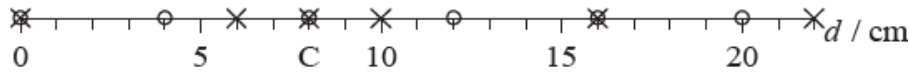
(ii) wavelength is 16cm;

and so speed is $v (= f\lambda = 5.0 \times 0.16) = 0.80 \text{ms}^{-1}$;

c. (i) points at 0, 8 and 16 cm stay in the same place;

points at 4 and 20 cm move 2 cm to the right;

point at 12 cm moves 2 cm to the left;



(ii) the point at 8 cm;

Examiners report

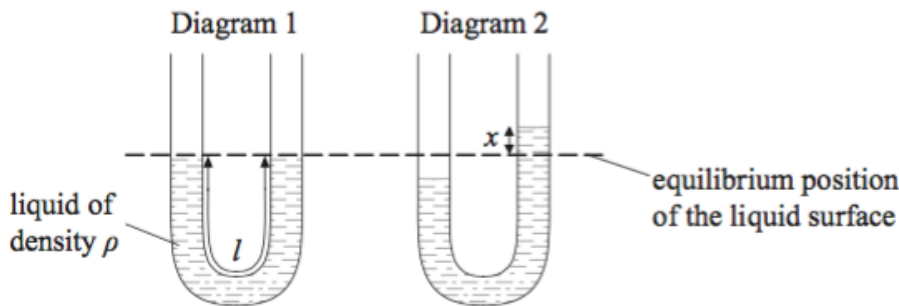
- a. [N/A]
 b. [N/A]
 c. [N/A]

This question is in **two** parts. **Part 1** is about simple harmonic motion (SHM) and a wave in a string. **Part 2** is about the unified atomic mass unit and a nuclear reaction.

Part 1 Simple harmonic motion and a wave in a string

- a. By reference to simple harmonic motion, state what is meant by amplitude.
 b. A liquid is contained in a U-tube.

[1]
 [5]



The pressure on the liquid in one side of the tube is increased so that the liquid is displaced as shown in diagram 2. When the pressure is suddenly released the liquid oscillates. The damping of the oscillations is small.

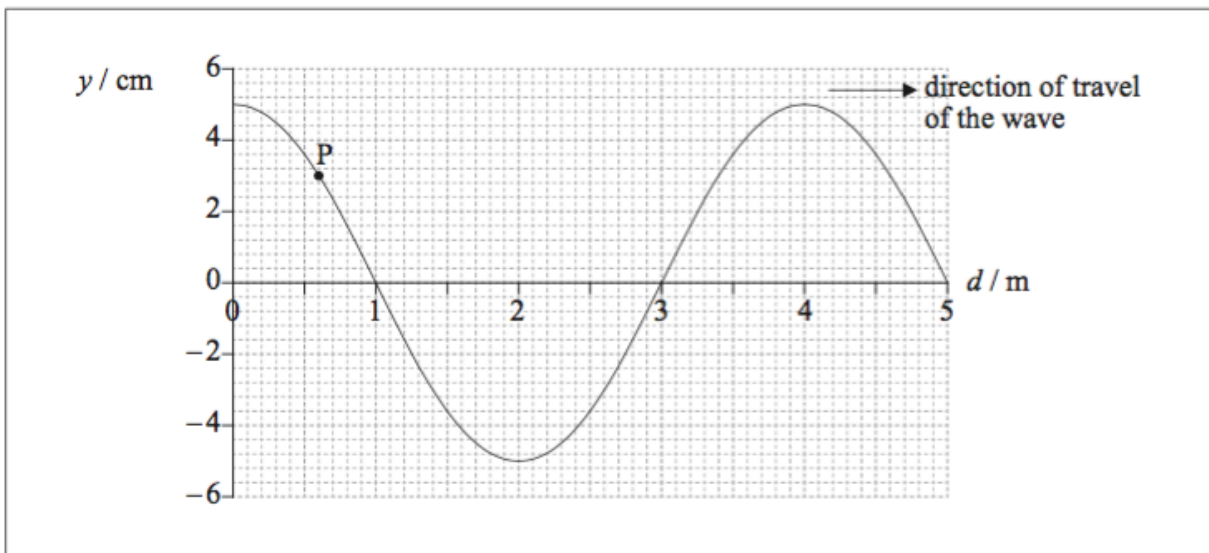
- (i) Describe what is meant by damping.
 (ii) The displacement of the liquid surface from its equilibrium position is x . The acceleration a of the liquid in the tube is given by the expression

$$a = -\frac{2g}{l}x$$

where g is the acceleration of free fall and l is the total length of the liquid column. The total length of the liquid column in the tube is 0.32m. Determine the period of oscillation.

- c. A wave is travelling along a string. The string can be modelled as a single line of particles and each particle executes simple harmonic motion. [9]
 The period of oscillation of the particles is 0.80s.

The graph shows the displacement y of part of the string at time $t=0$. The distance along the string is d .



- On the graph, draw an arrow to show the direction of motion of particle P at the point marked on the string.
- Determine the magnitude of the velocity of particle P.
- Show that the speed of the wave is 5.0 ms^{-1} .
- On the graph opposite, label with the letter X the position of particle P at $t=0.40 \text{ s}$.

Markscheme

a. the maximum displacement of the system from equilibrium/from centre of motion / *OWTTE*;

b. (i) the amplitude of the oscillations/(total) energy decreases (with time); because a force always opposes direction of motion/there is a resistive force/ there is a friction force;

Do not allow bald "friction".

$$(ii) \omega = \sqrt{\frac{2g}{l}};$$

$$T = 2\pi \sqrt{\frac{0.32}{2 \times 9.81}};$$

$$= 0.80 \text{ s};$$

c. (i) upwards;

$$(ii) y_0 = 0.050 \text{ (m)} \text{ and } y = 0.030 \text{ (m)};$$

$$\omega = \left(\frac{2\pi}{0.80} \right) = 7.85 \text{ (rads}^{-1}\text{)};$$

$$v = 7.85 \sqrt{[0.05]^2 - [0.03]^2};$$

$$= 0.31 \text{ ms}^{-1}; \text{ (allow working in cm to give } 31 \text{ cms}^{-1}\text{)};$$

$$(iii) \lambda = 4.0 \text{ m};$$

$$\text{recognition that } f = \frac{1}{0.80} (= 1.25);$$

$$(f\lambda =) v = 1.25 \times 4.0;$$

$$(= 5.0 \text{ ms}^{-1})$$

$$(iv) y = -3.0 \text{ cm, } d = 0.6 \text{ m};$$

Examiners report

- a.
- b.
- c.

This question is in **two** parts. **Part 1** is about solar radiation and the greenhouse effect. **Part 2** is about a mass on a spring.

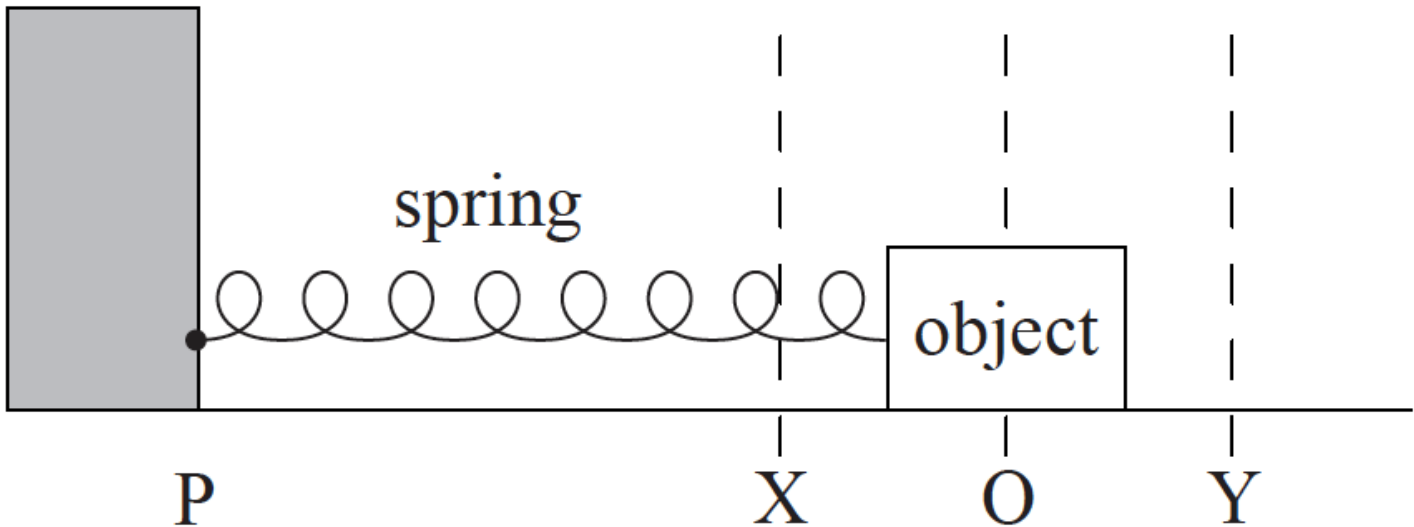
Part 1 Solar radiation and the greenhouse effect

The following data are available.

Quantity	Symbol	Value
Radius of Sun	R	$7.0 \times 10^8 \text{ m}$
Surface temperature of Sun	T	$5.8 \times 10^3 \text{ K}$
Distance from Sun to Earth	d	$1.5 \times 10^{11} \text{ m}$
Stefan-Boltzmann constant	σ	$5.7 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$

Part 2 A mass on a spring

An object is placed on a frictionless surface and attached to a light horizontal spring.



The other end of the spring is attached to a stationary point P. Air resistance is negligible. The equilibrium position is at O. The object is moved to position Y and released.

a. State the Stefan-Boltzmann law for a black body.

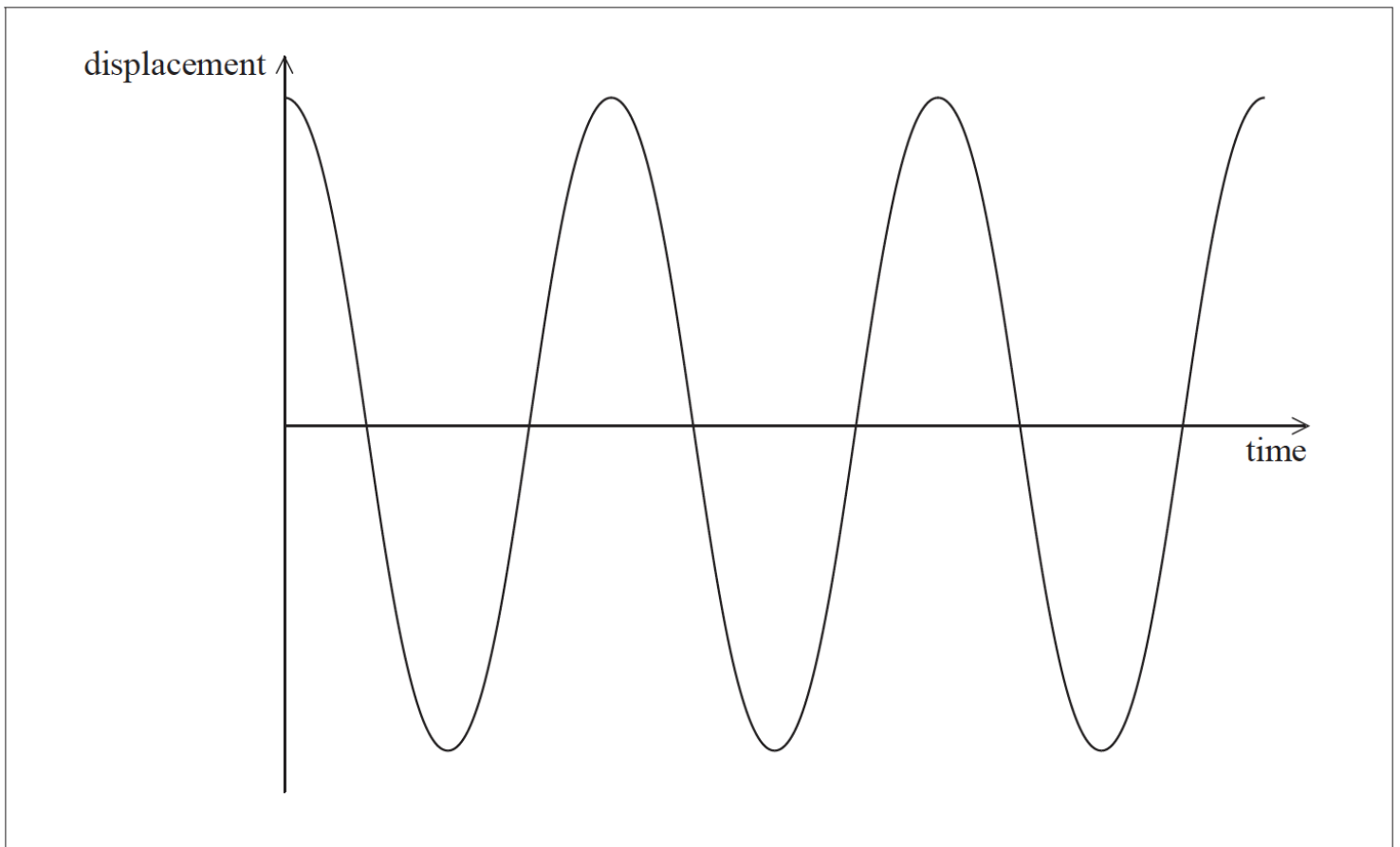
[2]

b. Deduce that the solar power incident per unit area at distance d from the Sun is given by

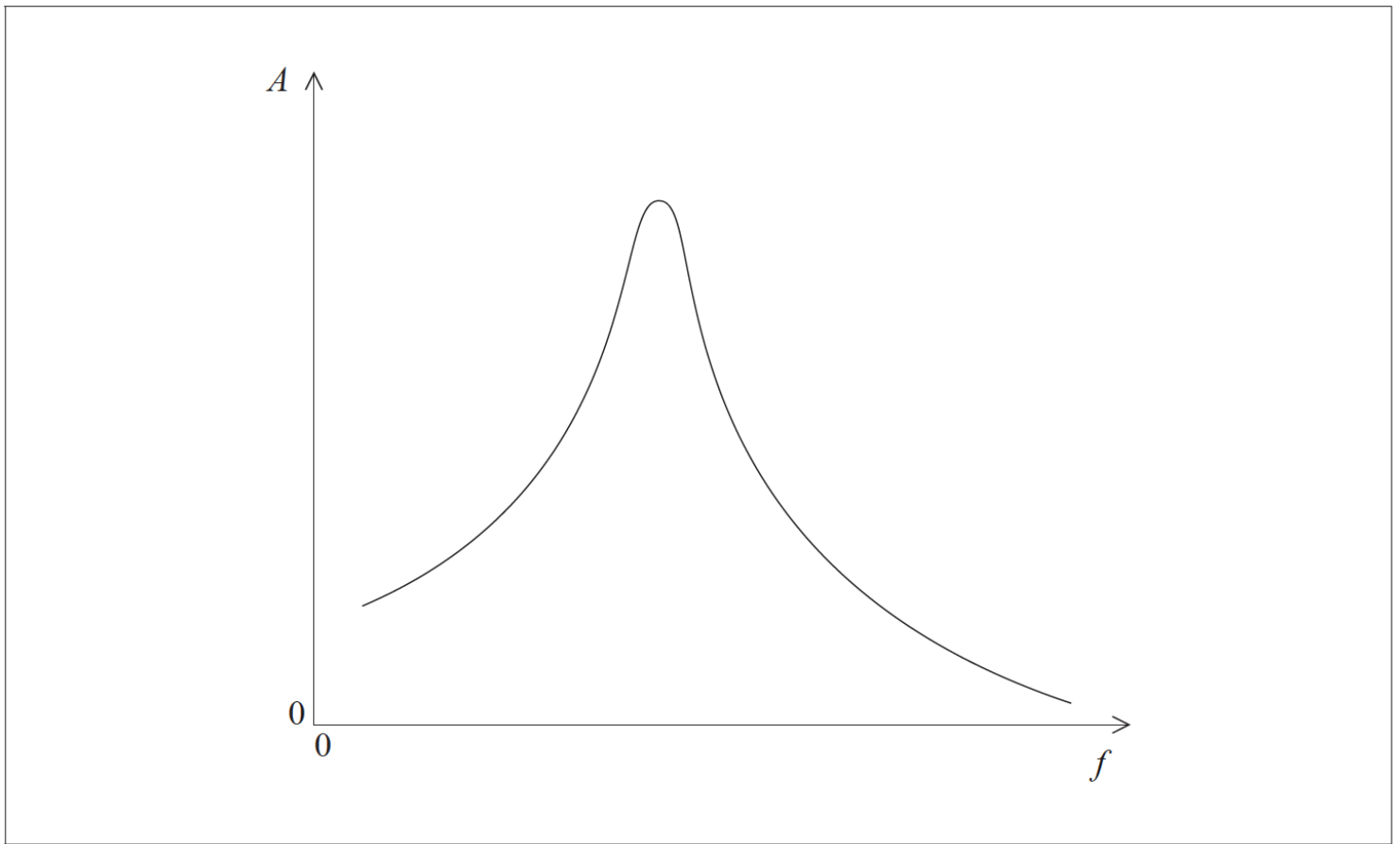
[2]

$$\frac{\sigma R^2 T^4}{d^2}$$

- c. Calculate, using the data given, the solar power incident per unit area at distance d from the Sun. [2]
- d. State **two** reasons why the solar power incident per unit area at a point on the surface of the Earth is likely to be different from your answer in (c). [2]
- e. The average power absorbed per unit area at the Earth's surface is 240Wm^{-2} . By treating the Earth's surface as a black body, show that the average surface temperature of the Earth is approximately 250K. [2]
- f. Explain why the actual surface temperature of the Earth is greater than the value in (e). [3]
- h. Outline the conditions necessary for the object to execute simple harmonic motion. [2]
- i. The sketch graph below shows how the displacement of the object from point O varies with time over three time periods. [4]



- (i) Label with the letter A a point at which the magnitude of the acceleration of the object is a maximum.
- (ii) Label with the letter V a point at which the speed of the object is a maximum.
- (iii) Sketch on the same axes a graph of how the displacement varies with time if a **small** frictional force acts on the object.
- j. Point P now begins to move from side to side with a small amplitude and at a variable driving frequency f . The frictional force is still small. [4]
- At each value of f , the object eventually reaches a constant amplitude A .
- The graph shows the variation with f of A .



(i) With reference to resonance and resonant frequency, comment on the shape of the graph.

(ii) On the same axes, draw a graph to show the variation with f of A when the frictional force acting on the object is increased.

Markscheme

a. power/energy per second emitted proportional to surface area;

and proportional to fourth power of absolute temperature / temperature in K;

Accept equation with symbols defined.

b. solar power given by $4\pi R^2 \sigma T^4$;

spreads out over sphere of surface area $4\pi d^2$;

Hence equation given.

$$c. \left(\frac{\sigma R^2 T^4}{d^2} \right) = \frac{5.7 \times 10^{-8} \times [7.0 \times 10^8]^2 \times [5.8 \times 10^3]^4}{[1.5 \times 10^{11}]^2};$$

$$= 1.4 \times 10^3 (\text{Wm}^{-2});$$

Award [2] for a bald correct answer.

d. some energy reflected;

some energy absorbed/scattered by atmosphere; depends on latitude;

depends on time of day;

depends on time of year;

depends on weather (eg cloud cover) at location; power output of Sun varies;

Earth-Sun distance varies;

e. power radiated = power absorbed;

$$T = \sqrt[4]{\frac{240}{5.7 \times 10^{-8}}} = (250\text{K});$$

Accept answers given as 260 (K).

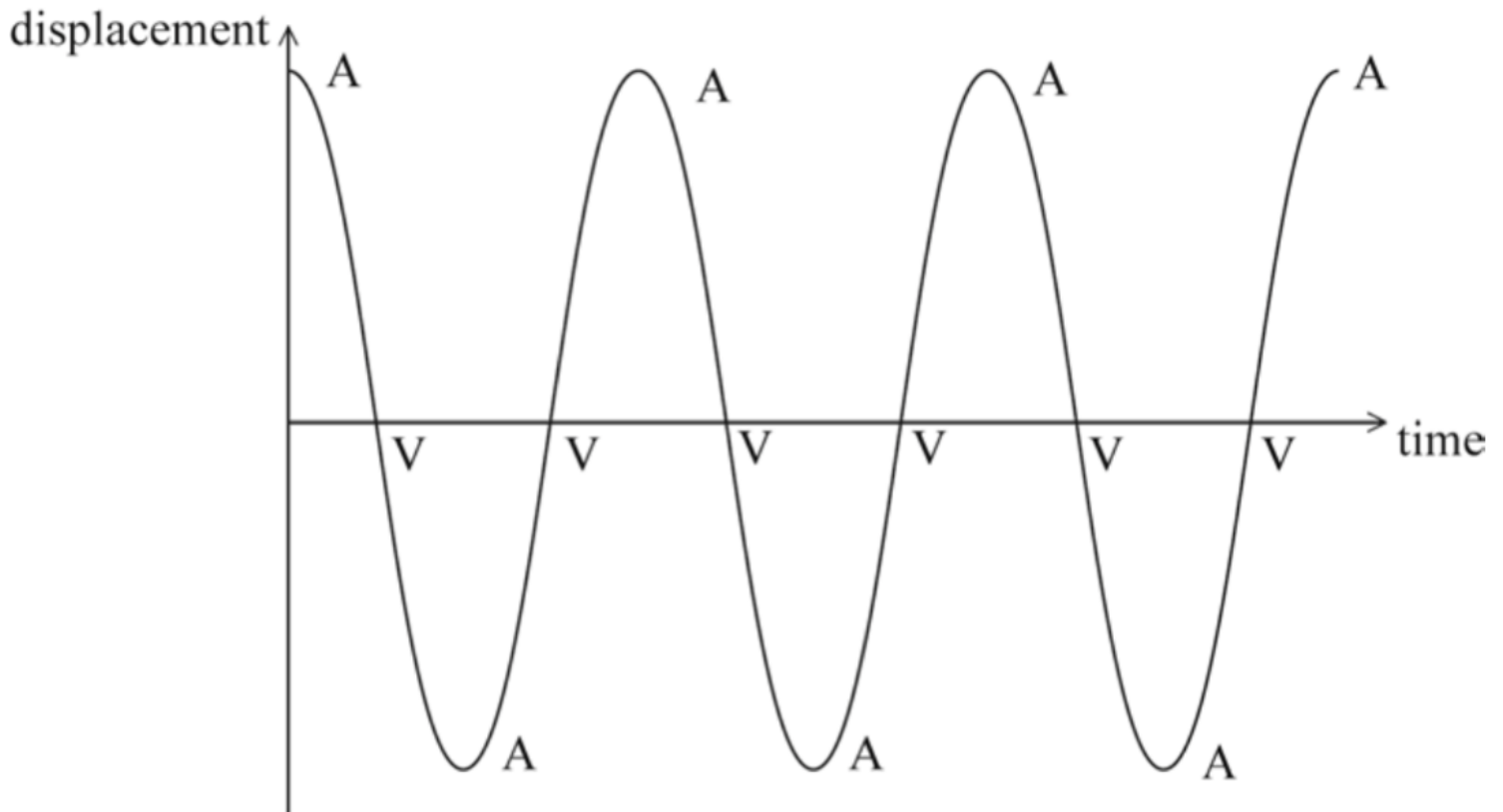
f. radiation from Sun is re-emitted from Earth at longer wavelengths; greenhouse gases in the atmosphere absorb some of this energy; and radiate some of it back to the surface of the Earth;

h. the force (of the spring on the object)/acceleration (of the object/point O) must be proportional to the displacement (from the equilibrium position/centre/point O);

and in the opposite direction to the displacement / always directed towards the equilibrium position/centre/point O;

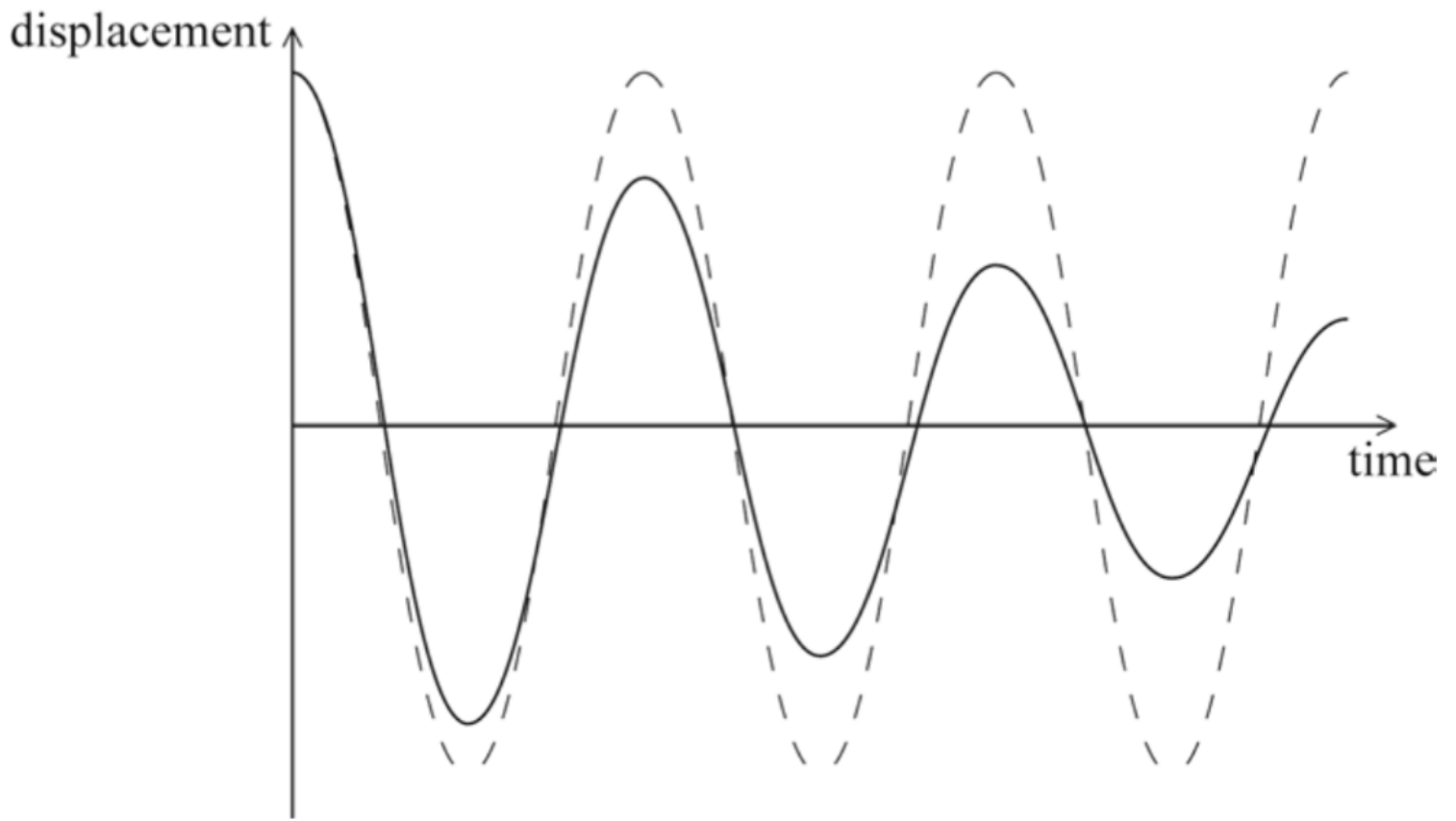
i. (i) one A correctly shown;

(ii) one V correctly shown;



(iii) same period; (judge by eye)

amplitude decreasing with time;

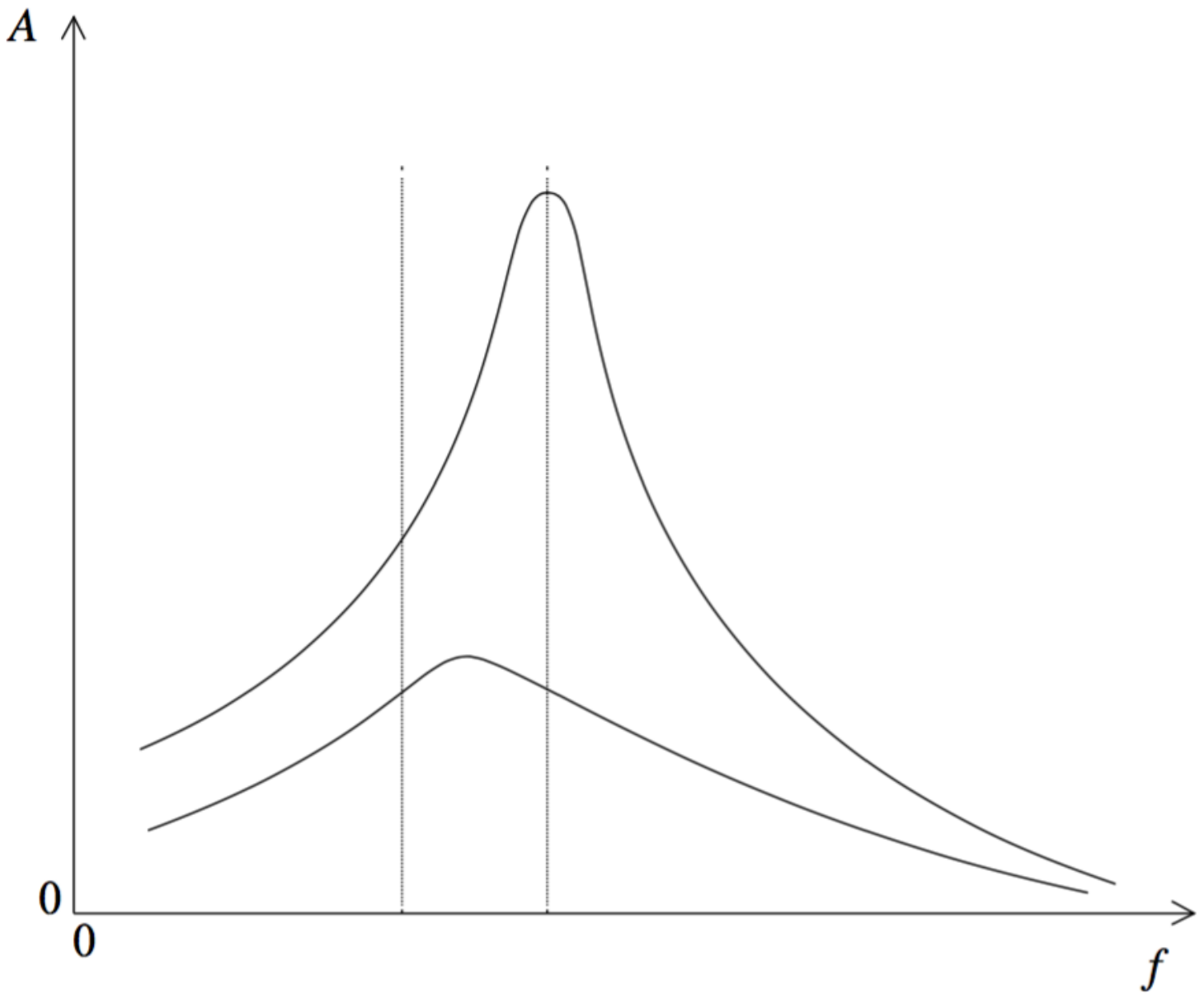


j. (i) resonance is where driving frequency equals/is close to natural/resonant frequency;

the natural/resonant frequency is at/near the maximum amplitude of the graph;

(ii) lower amplitude everywhere on graph, bit still positive;

maximum in same place/moved slightly (*that is, between the lines*) to left on graph;



Examiners report

- The Stefan-Boltzmann law was poorly understood with few candidates stating that the absolute temperature is raised to the fourth power.
- This question was poorly done with few candidates substituting the surface area of the sun or the surface area of a sphere at the Earth's radius of orbit.
- Despite not being able to state or manipulate the Stefan-Boltzmann law most candidates could substitute values into the expression and calculate a result.
- This question was well answered at higher level.
- To show the given value there is the requirement for an explanation of why the incident power absorbed by the Earth's surface is equal to the power radiated by the Earth, few candidates were successful in this aspect. Although most could substitute into the Stefan-Boltzmann equation they needed to either show that the fourth root was used or to find the temperature to more significant figures than the value given.
- A surprising number of candidates could not explain the greenhouse effect. A common misunderstanding was that the Earth reflected radiation into the atmosphere and that the atmosphere reflected the radiation back to the Earth.

- h. The conditions for simple harmonic motion were poorly outlined by most candidates. Few identified a relationship between force/acceleration and displacement, with most talking about it going backwards and forwards without slowing down.
 - i. This question was well answered by many. The only notable mistake was with reducing the time period of the damped oscillation.
 - j. i) Identifying the peak of the graph with the resonant frequency was broadly successfully done but not many candidates stated that this occurs when the driving frequency is equal to the natural frequency.
ii) This sketch was generally well done.
-