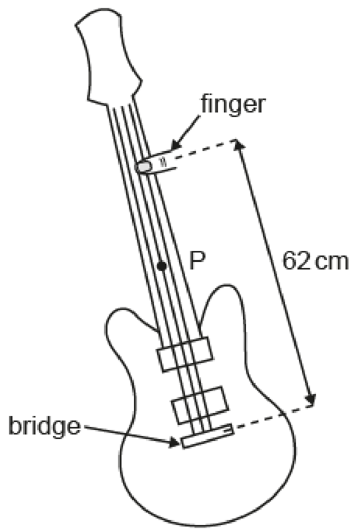
Red 3 HL ONLY [most common] *[135 marks]*

On a guitar, the strings played vibrate between two fixed points. The frequency of vibration is modified by changing the string length using a finger. The different strings have different wave speeds. When a string is plucked, a standing wave forms between the bridge and the finger.



1a. Outline how a standing wave is produced on the string. *[2 marks]*

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The string is displaced 0.4 cm at point P to sound the guitar. Point P on the string vibrates with simple harmonic motion (shm) in its first harmonic with a frequency of 195 Hz. The sounding length of the string is 62 cm.

1b. Show that the speed of the wave on the string is about 240 m s^{-1}. *[2 marks]*

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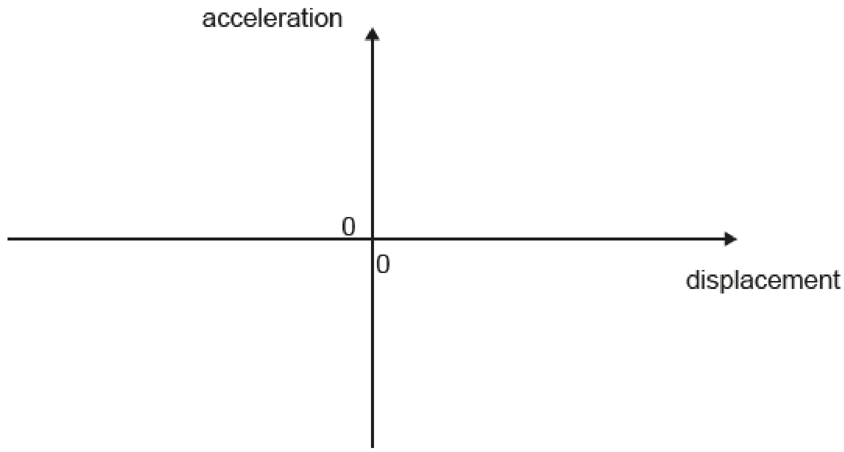
1c. Sketch a graph to show how the acceleration of point P varies with its displacement from the rest position. *[1 mark]*



1d. Calculate, in $m\,s^{-1}$, the maximum velocity of vibration of point P when it is vibrating with a frequency of 195 Hz. *[2 marks]*

1e. Calculate, in terms of g, the maximum acceleration of P. *[2 marks]*

1f. Estimate the displacement needed to double the energy of the string. *[2 marks]*

1g. The string is made to vibrate in its third harmonic. State the distance between consecutive nodes. *[1 mark]*

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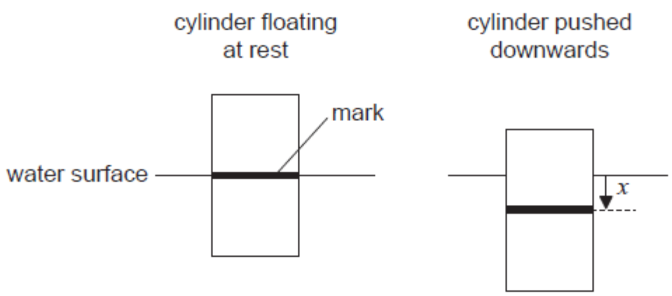
A vertical solid cylinder of uniform cross-sectional area A floats in water. The cylinder is partially submerged. When the cylinder floats at rest, a mark is aligned with the water surface. The cylinder is pushed vertically downwards so that the mark is a distance x below the water surface.



At time $t = 0$ the cylinder is released. The resultant vertical force F on the cylinder is related to the displacement x of the mark by

$$F = -\rho A g x$$

where ρ is the density of water.

2a. Outline why the cylinder performs simple harmonic motion when released. *[1 mark]*

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2b. The mass of the cylinder is $118\ \mathrm{kg}$ and the cross-sectional area of the cylinder is $2.29 \times 10^{-1}\ \mathrm{m}^2$. The density of water is $1.03 \times 10^3\ \mathrm{kg\ m}^{-3}$. Show that the angular frequency of oscillation of the cylinder is about $4.4\ \ \mathrm{rad\ s}^{-1}$. *[2 marks]*

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The cylinder was initially pushed down a distance $x = 0.250\ \mathrm{m}$.

2c. Determine the maximum kinetic energy E_{kmax} of the cylinder. *[2 marks]*

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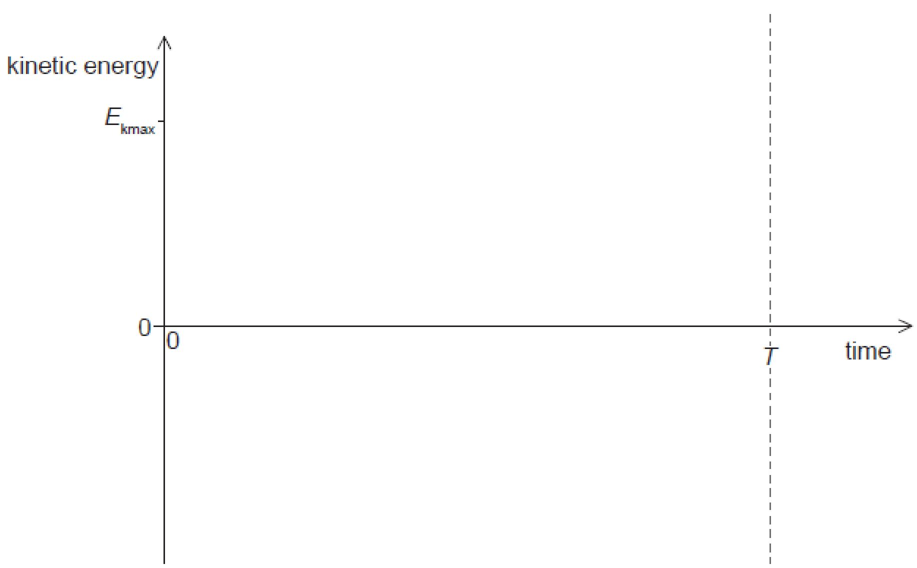
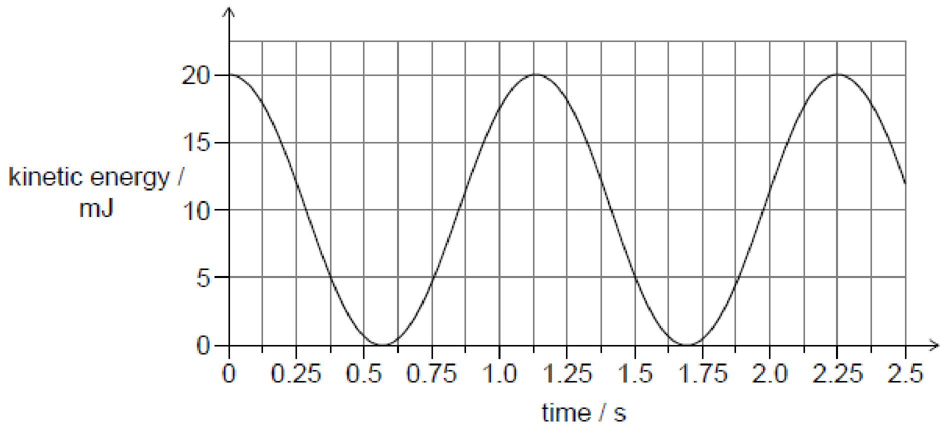
2d. Draw, on the axes, the graph to show how the kinetic energy of the cylinder varies with time during **one** period of oscillation T. *[2 marks]*



A small metal pendulum bob is suspended at rest from a fixed point with a length of thread of negligible mass. Air resistance is negligible.

The pendulum begins to oscillate. Assume that the motion of the system is simple harmonic, and in one vertical plane.

The graph shows the variation of kinetic energy of the pendulum bob with time.



3a. Calculate, in m, the length of the thread. State your answer to an appropriate number of significant figures. *[3 marks]*

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3b. Label on the graph with the letter X a point where the speed of the pendulum is half that of its initial speed. *[1 mark]*

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3c. The mass of the pendulum bob is 75 g. Show that the maximum speed of the bob is about 0.7 m s^{-1}. *[2 marks]*

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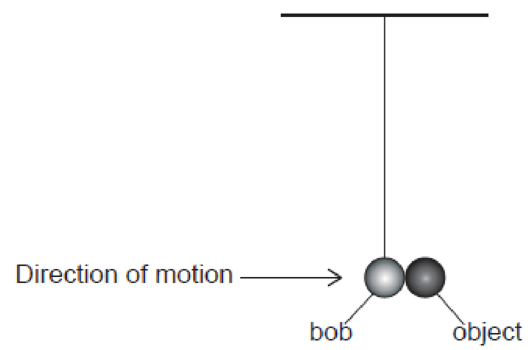
When the 75 g bob is moving horizontally at 0.80 m s^{-1}, it collides with a small stationary object also of mass 75 g. The object and the bob stick together.



3d. Calculate the speed of the combined masses immediately after the collision. *[1 mark]*

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3e. Show that the collision is inelastic. *[3 marks]*

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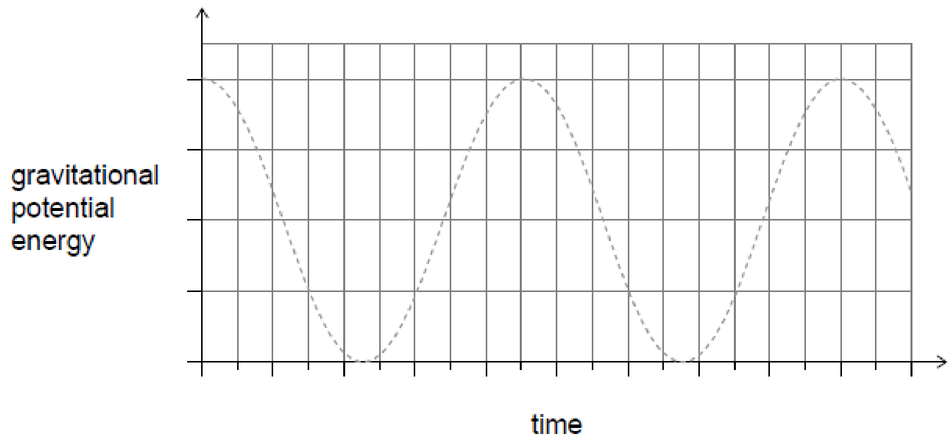
3f. Sketch, on the axes, a graph to show the variation of gravitational potential energy with time for the bob and the object after the collision. The data from the graph used in (a) is shown as a dashed line for reference. *[2 marks]*



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3g. The speed after the collision of the bob and the object was measured using a sensor. This sensor emits a sound of frequency *f* and this sound is reflected from the moving bob. The sound is then detected by the sensor as frequency *f′*. *[3 marks]*

Explain why *f* and *f′* are different.

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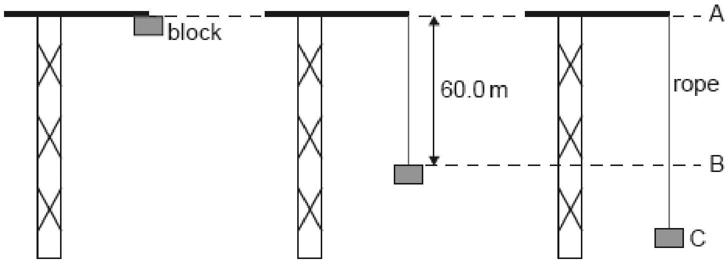
An elastic climbing rope is tested by fixing one end of the rope to the top of a crane. The other end of the rope is connected to a block which is initially at position A. The block is released from rest. The mass of the rope is negligible.



The unextended length of the rope is 60.0 m. From position A to position B, the block falls freely.

4a. At position B the rope starts to extend. Calculate the speed of the block at position B. *[2 marks]*

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At position C the speed of the block reaches zero. The time taken for the block to fall between B and C is 0.759 s. The mass of the block is 80.0 kg.

4b. Determine the magnitude of the average resultant force acting on the block between B and C. *[2 marks]*

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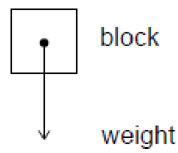
4c. Sketch on the diagram the average resultant force acting on the block between B and C. The arrow on the diagram represents the weight of the block. *[2 marks]*



4d. Calculate the magnitude of the average force exerted by the rope on the block between B and C. *[2 marks]*

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For the rope and block, describe the energy changes that take place

4e. between A and B. *[1 mark]*

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4f. between B and C. *[1 mark]*

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4g. The length reached by the rope at C is 77.4 m. Suggest how energy considerations could be used to determine the elastic constant of the rope. *[2 marks]*

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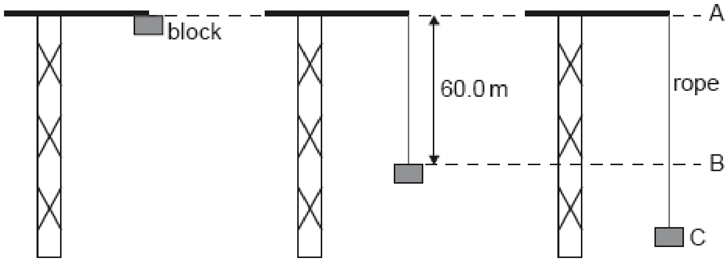
An elastic climbing rope is tested by fixing one end of the rope to the top of a crane. The other end of the rope is connected to a block which is initially at position A. The block is released from rest. The mass of the rope is negligible.



The unextended length of the rope is 60.0 m. From position A to position B, the block falls freely.

In another test, the block hangs in equilibrium at the end of the same elastic rope. The elastic constant of the rope is 400 Nm^{-1}. The block is pulled 3.50 m vertically below the equilibrium position and is then released from rest.

4h. Calculate the time taken for the block to return to the equilibrium position for the first time. *[2 marks]*

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4i. Calculate the speed of the block as it passes the equilibrium position. *[2 marks]*

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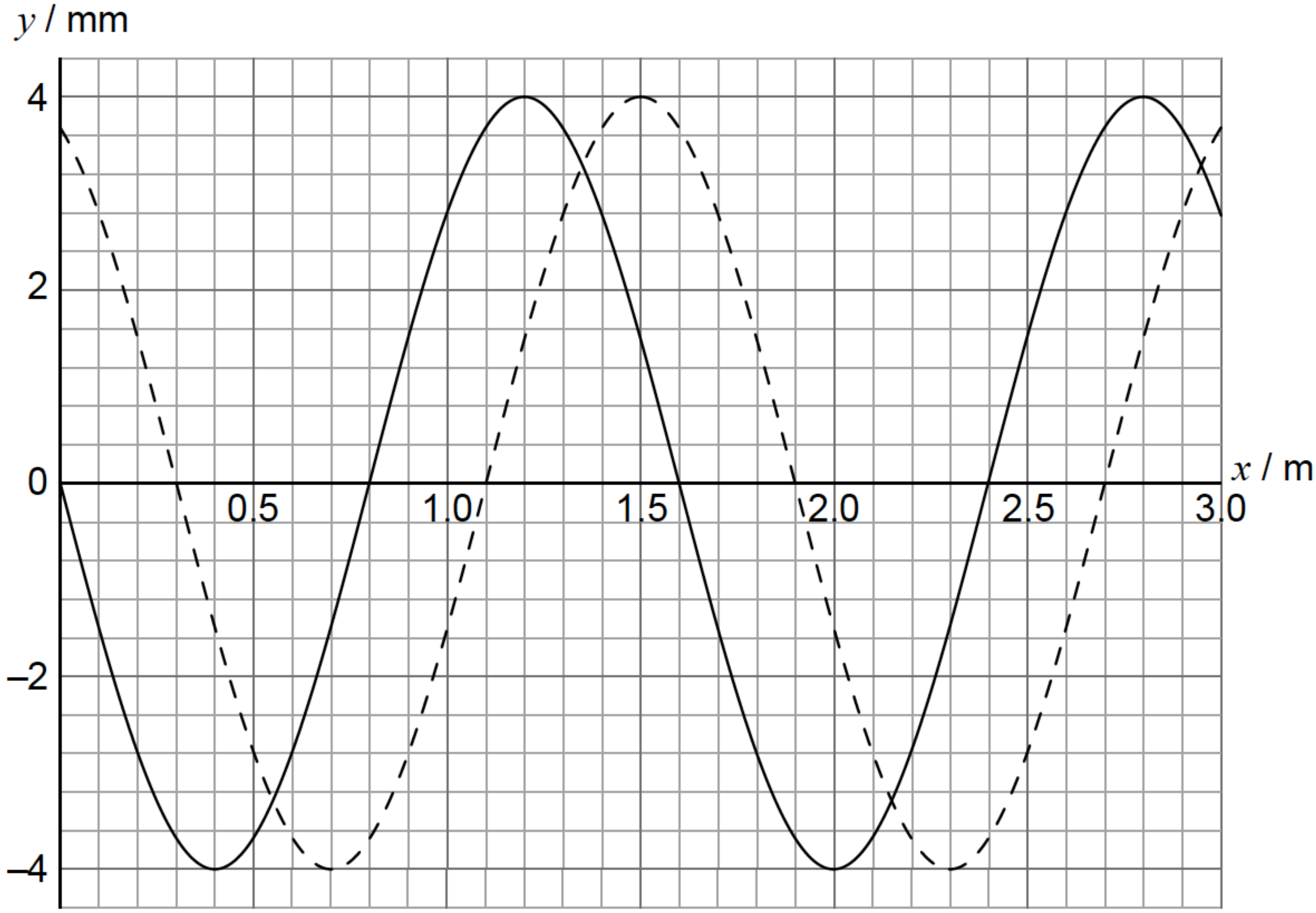
A longitudinal wave is travelling in a medium from left to right. The graph shows the variation with distance *x* of the displacement *y* of the particles in the medium. The solid line and the dotted line show the displacement at $t=0$ and $t=0.882$ ms, respectively.



The period of the wave is greater than 0.882 ms. A displacement to the right of the equilibrium position is positive.

5a. (i) Calculate the speed of this wave. *[4 marks]*

(ii) Show that the angular frequency of oscillations of a particle in the medium is $\omega=1.3\times10^{3}\text{rad}\,\text{s}^{-1}$.

5b. One particle in the medium has its equilibrium position at x=1.00 m. *[4 marks]*

(i) State and explain the direction of motion for this particle at t=0.

(ii) Show that the speed of this particle at t=0.882 ms is 4.9ms^{-1}.

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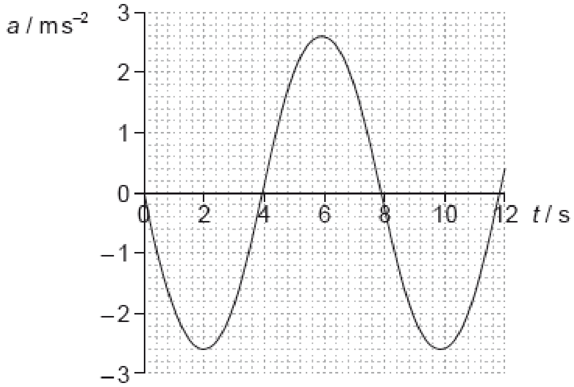
5c. The travelling wave in (b) is directed at the open end of a tube of length 1.20 m. The other end of the tube is closed. *[3 marks]*

(i) Describe how a standing wave is formed.

(ii) Demonstrate, using a calculation, that a standing wave will be established in this tube.

This question is about simple harmonic motion (SHM).

The graph shows the variation with time t of the acceleration a of an object X undergoing simple harmonic motion (SHM).



6a. Define *simple harmonic motion (SHM)*. *[2 marks]*

6b. X has a mass of 0.28 kg. Calculate the maximum force acting on X. *[1 mark]*

6c. Determine the maximum displacement of X. Give your answer to an appropriate number of significant figures. *[4 marks]*

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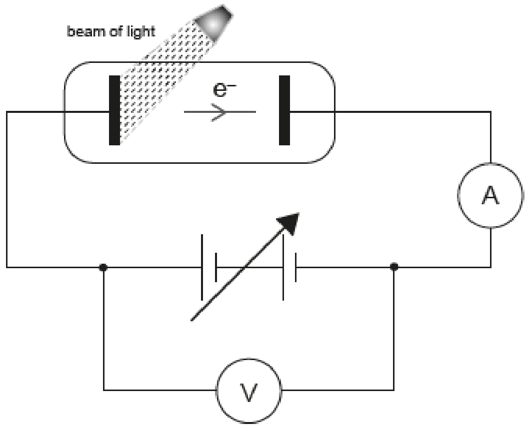
6d. A second object Y oscillates with the same frequency as X but with a phase difference of $\frac{\pi}{4}$. Sketch, using the graph opposite, how the acceleration of object Y varies with t. *[2 marks]*

In an electric circuit used to investigate the photoelectric effect, the voltage is varied until the reading in the ammeter is zero. The stopping voltage that produces this reading is 1.40 V.



7a. Describe the photoelectric effect. *[2 marks]*

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7b. Show that the maximum velocity of the photoelectrons is $700\ \mathrm{km\,s^{-1}}$. *[2 marks]*

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7c. The photoelectrons are emitted from a sodium surface. Sodium has a work function of 2.3 eV. *[3 marks]*

Calculate the wavelength of the radiation incident on the sodium. State an appropriate unit for your answer.

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Monochromatic light of very low intensity is incident on a metal surface. The light causes the emission of electrons almost instantaneously. Explain how this observation

8a. does not support the wave nature of light. *[2 marks]*

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8b. does support the photon nature of light. *[2 marks]*

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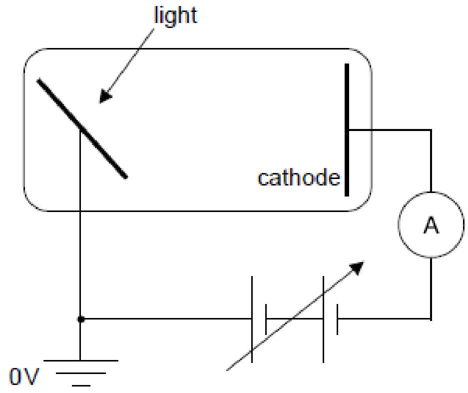
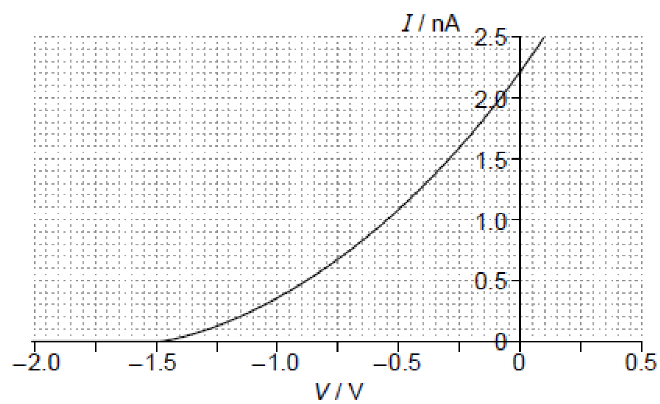
In an experiment to demonstrate the photoelectric effect, light of wavelength 480 nm is incident on a metal surface.



The graph shows the variation of the current I in the ammeter with the potential V of the cathode.



8c. Calculate, in eV, the work function of the metal surface. *[3 marks]*

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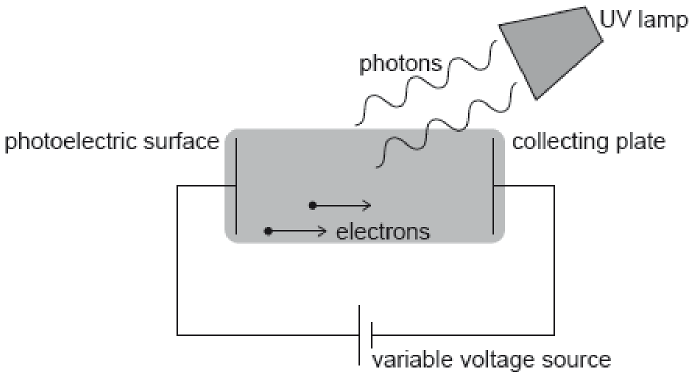
8d. The intensity of the light incident on the surface is reduced by half without changing the wavelength. Draw, on the graph, the variation of the current I with potential V after this change. *[2 marks]*

Hydrogen atoms in an ultraviolet (UV) lamp make transitions from the first excited state to the ground state. Photons are emitted and are incident on a photoelectric surface as shown.



9a. Show that the energy of photons from the UV lamp is about 10 eV. *[2 marks]*

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The photons cause the emission of electrons from the photoelectric surface. The work function of the photoelectric surface is 5.1 eV.

9b. Calculate, in J, the maximum kinetic energy of the emitted electrons. *[2 marks]*

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9c. Suggest, with reference to conservation of energy, how the variable voltage source can be used to stop all emitted electrons from reaching the collecting plate. *[2 marks]*

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9d. The variable voltage can be adjusted so that no electrons reach the collecting plate. Write down the minimum value of the voltage for which no electrons reach the collecting plate. *[1 mark]*

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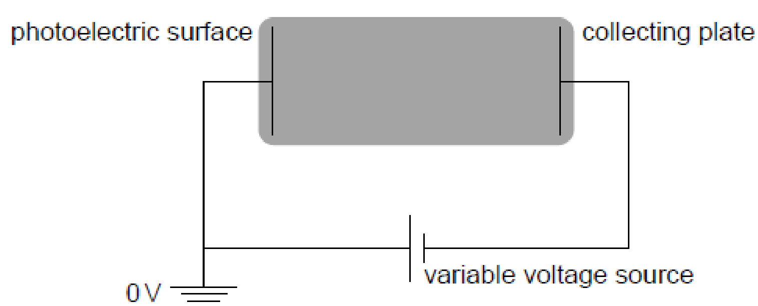
The electric potential of the photoelectric surface is 0 V. The variable voltage is adjusted so that the collecting plate is at –1.2 V.



9e. On the diagram, draw and label the equipotential lines at –0.4 V and –0.8 V. *[2 marks]*

9f. An electron is emitted from the photoelectric surface with kinetic energy 2.1 eV. Calculate the speed of the electron at the collecting plate. *[2 marks]*

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Two observations about the photoelectric effect are

Observation 1: For light below the threshold frequency no electrons are emitted from the metal surface.

Observation 2: For light above the threshold frequency, the emission of electrons is almost instantaneous.

10a. Explain how each observation provides support for the particle theory but not the wave theory of light. *[4 marks]*

Observation 1: . . . .

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Observation 2: . . . .

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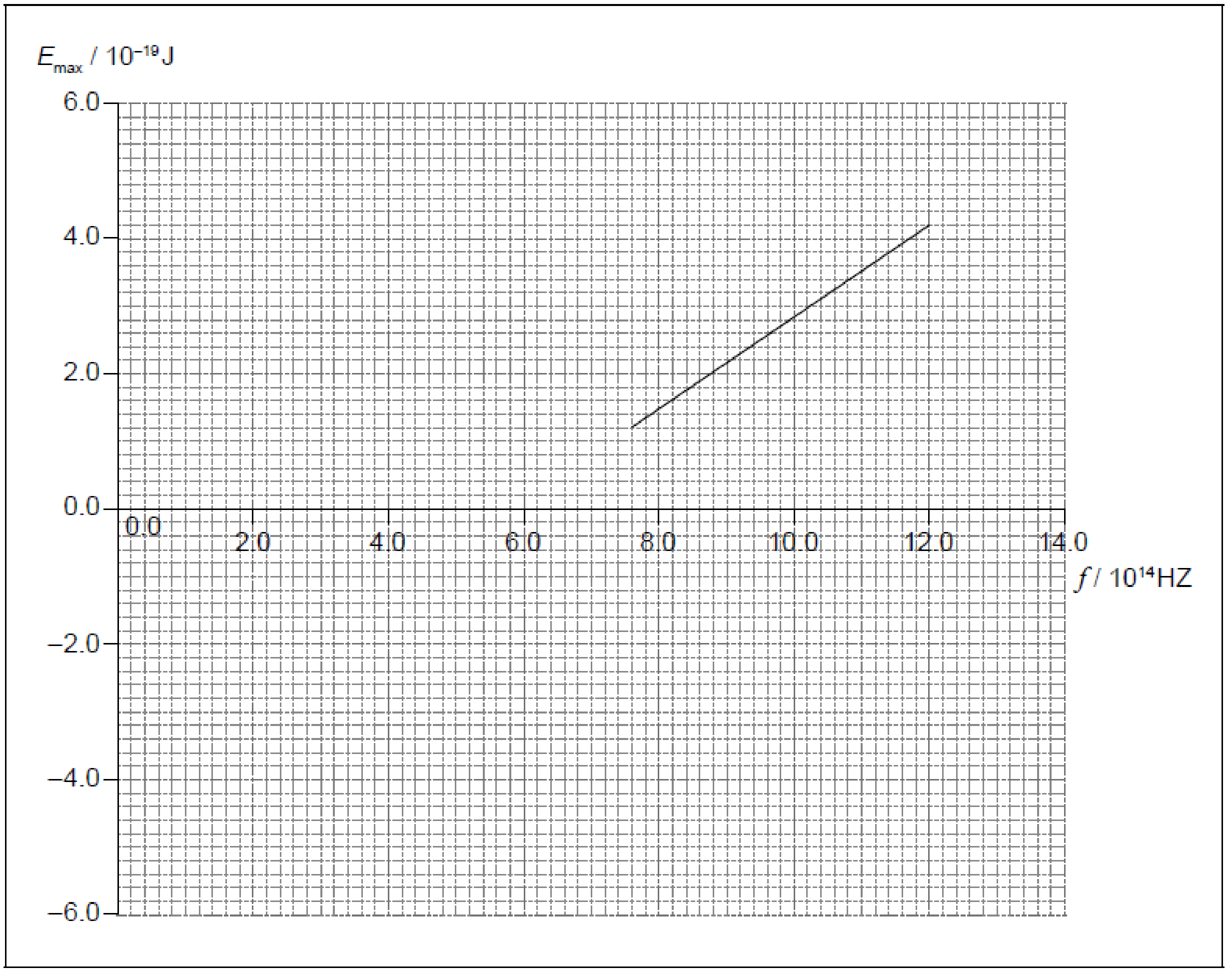
The graph shows how the maximum kinetic energy E_{max} of electrons emitted from a surface of barium metal varies with the frequency f of the incident radiation.



10b. Determine a value for Planck’s constant. *[2 marks]*

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10c. State what is meant by the work function of a metal. *[1 mark]*

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10d. Calculate the work function of barium in eV. *[2 marks]*

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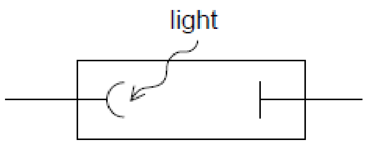
10e. The experiment is repeated with a metal surface of cadmium, which has a greater work function. Draw a second line on the graph to represent the results of this experiment. *[2 marks]*

Yellow light of photon energy 3.5 x 10^{-19} J is incident on the surface of a particular photocell.



11a. Calculate the wavelength of the light. *[1 mark]*

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11b. Electrons emitted from the surface of the photocell have almost no kinetic energy. Explain why this does not contradict the law of conservation of energy. *[2 marks]*

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11c. Radiation of photon energy 5.2×10^{-19} J is now incident on the photocell. Calculate the maximum velocity of the emitted electrons. *[2 marks]*

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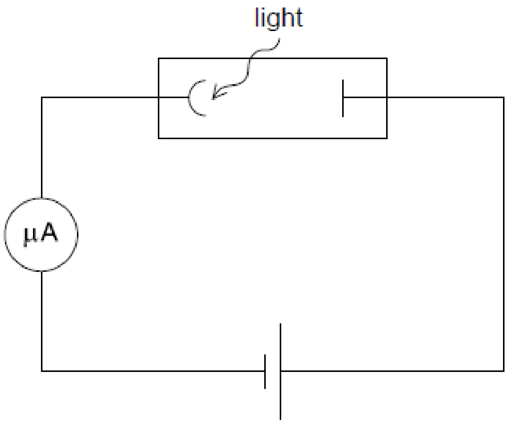
The photocell is connected to a cell as shown. The photoelectric current is at its maximum value (the saturation current).



Radiation with a greater photon energy than that in (b) is now incident on the photocell. The intensity of this radiation is the same as that in (b).

11d. Describe the change in the number of photons per second incident on the surface of the photocell. *[1 mark]*

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11e. State and explain the effect on the maximum photoelectric current as a result of increasing the photon energy in this way. *[3 marks]*

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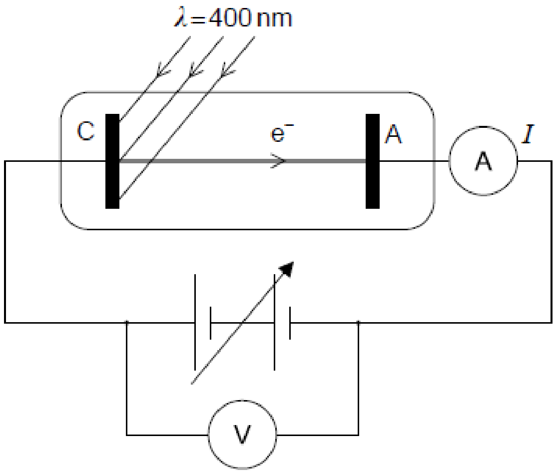
An apparatus is used to investigate the photoelectric effect. A caesium cathode C is illuminated by a variable light source. A variable power supply is connected between C and the collecting anode A. The photoelectric current *I* is measured using an ammeter.



12a. A current is observed on the ammeter when violet light illuminates C. With V held constant the current becomes zero when the violet light is replaced by red light of the same intensity. Explain this observation. *[3 marks]*

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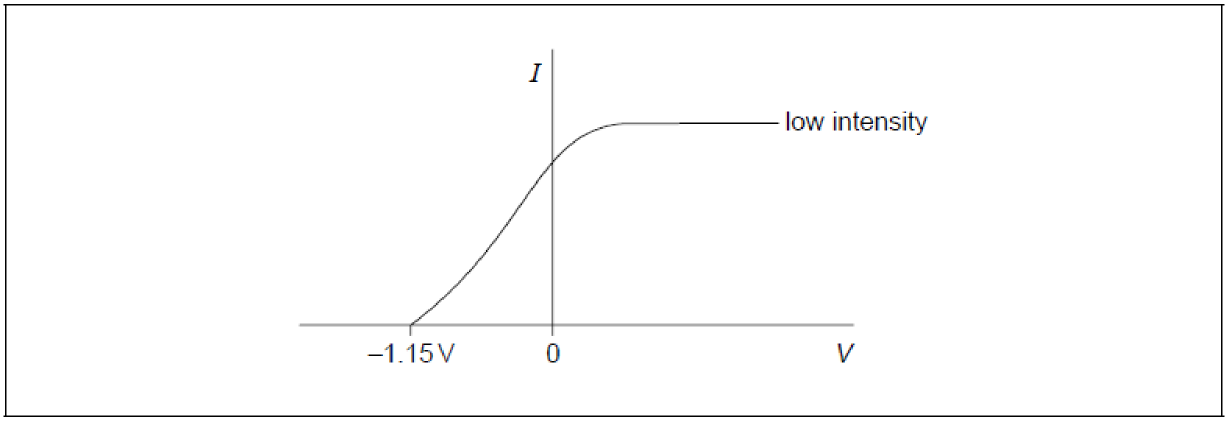
12b. The graph shows the variation of photoelectric current *I* with potential difference *V* between C and A when violet light of a particular intensity is used. *[6 marks]*



The intensity of the light source is increased without changing its wavelength.

(i) Draw, on the axes, a graph to show the variation of *I* with *V* for the increased intensity.

(ii) The wavelength of the violet light is 400 nm. Determine, in eV, the work function of caesium.

(iii) *V* is adjusted to +2.50V. Calculate the maximum kinetic energy of the photoelectrons just before they reach A.

This question is about the photoelectric effect.

13a. Outline why the wave model of light cannot account for the photoelectric effect. *[3 marks]*

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Monochromatic light of wavelength 420 nm is incident on a clean metal surface. The work function of the metal is $2.6 \times 10^{-19}\,\mathrm{J}$.

13b. Calculate, in eV, the maximum kinetic energy of the photoelectrons emitted. *[3 marks]*

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13c. The intensity of the light is $5.1 \mu\mathrm{W\,m^{-2}}$. Determine the number of photoelectrons emitted per second for each $\mathrm{mm^2}$ of the metal surface. Each photon has a 1 in 800 chance of ejecting an electron. *[3 marks]*

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