PapaCambridge

Cambridge International AS & A Level

PHYSICS

Paper 4

Topical Past Paper Questions
+ Answer Scheme

2016 - 2021

PapaCambridge

Chapter 15

Quantum physics

338. 9702_s21_qp_41 Q: 12

(a) Electromagnetic radiation of a single constant frequency is incident on a metal surface. This causes an electron to be emitted.

Explain why the maximum kinetic energy of the electron is independent of the intensity of the incident radiation.

....

....

....

....

.... [3]

(b) Ultraviolet radiation of wavelength 250 nm is incident on the surface of a sheet of zinc. The maximum kinetic energy of the emitted electrons is 1.4 eV.

Determine, in eV:

(i) the energy of a photon of the ultraviolet radiation

energy = ... eV [3]

(ii) the work function energy of the surface of the zinc.

energy = ... eV [2]

[Total: 8]

339. 9702_s21_qp_43 Q: 12

(a) Electromagnetic radiation of a single constant frequency is incident on a metal surface. This causes an electron to be emitted.

Explain why the maximum kinetic energy of the electron is independent of the intensity of the incident radiation.

....

....

....

....

.... [3]

(b) Ultraviolet radiation of wavelength 250 nm is incident on the surface of a sheet of zinc. The maximum kinetic energy of the emitted electrons is 1.4 eV.

Determine, in eV:

(i) the energy of a photon of the ultraviolet radiation

energy = ... eV [3]

(ii) the work function energy of the surface of the zinc.

energy = ... eV [2]

[Total: 8]

340. 9702_w21_qp_42 Q: 9

(a) State what is meant by:

(i) the *photoelectric effect*

....

....

.... [2]

(ii) *work function energy*.

....

.... [1]

(b) A polished calcium plate in a vacuum is investigated by illuminating the surface with light.

It is found that no photoelectric current is produced when the frequency of the light is less than 6.93×10^{14} Hz.

(i) State the name of the frequency below which no photoelectric current is produced.

.... [1]

(ii) Explain how the photon model of electromagnetic radiation accounts for this phenomenon.

....

....

....

.... [3]

(iii) Calculate the work function energy, in eV, of calcium.

work function energy = ... eV [2]

[Total: 9]

341. 9702_m20_qp_42 Q: 10

(a) By reference to the photoelectric effect, explain what is meant by *work function energy*.

....

....

.... [2]

(b) In an experiment, electromagnetic radiation of frequency f is incident on a metal surface.

The results in Fig. 10.1 show the variation with frequency f of the maximum kinetic energy E_{MAX} of electrons emitted from the surface.

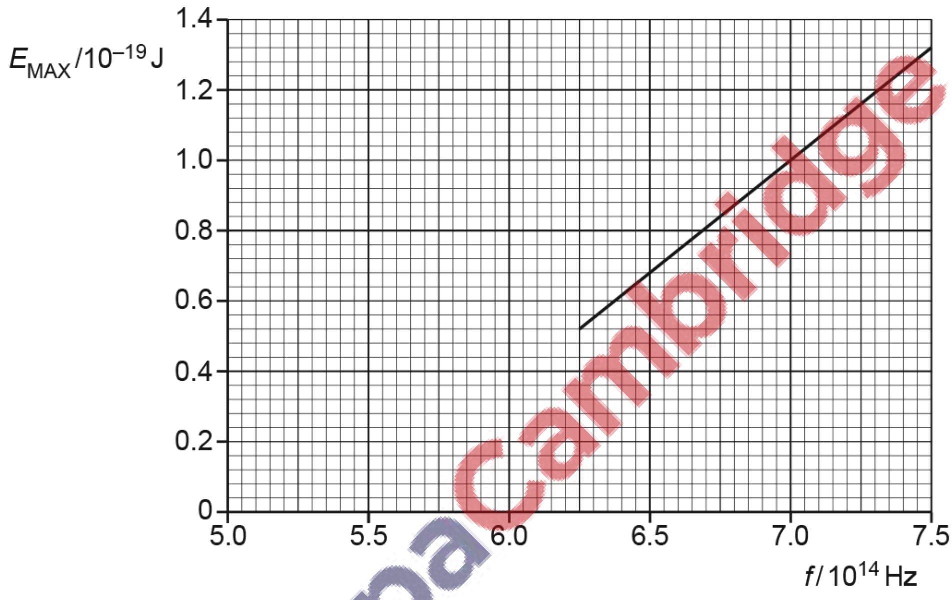

Fig. 10.1

(i) Determine the work function energy in J of the metal used in the experiment.

work function energy = ... J [2]

(ii) The work function energy in eV for some metals is given in Table 10.1.

Table 10.1

metal	work function / eV
tungsten	4.49
magnesium	3.68
potassium	2.26

Determine the metal used in the experiment. Show your working.

....

.... [1]

(c) The intensity of the electromagnetic radiation for one particular frequency in **(b)** is increased.

State and explain the change, if any, in:

(i) the maximum kinetic energy of the emitted electrons

....

.... [1]

(ii) the rate of emission of photoelectrons.

....

.... [1]

[Total: 7]

342. 9702_s19_qp_43 Q: 11

(a) State **three** pieces of evidence provided by the photoelectric effect for a particulate nature of electromagnetic radiation.

1. ....

....

2. ....

....

3. ....

.... [3]

(b) The work function energies of some metals are shown in Fig. 11.1.

	work function energy / eV
sodium	2.4
calcium	2.9
zinc	3.6
silver	4.3

Fig. 11.1

Each metal is irradiated with electromagnetic radiation of wavelength 380 nm.

(i) Calculate the energy, in eV, of a photon of electromagnetic radiation of wavelength 380 nm.

energy = ... eV [3]

(ii) Determine which metals will give rise to the emission of photoelectrons. Explain your answer.

....

.... [2]

(c) Photons of wavelength 380 nm are incident normally on a metal surface at a rate of $7.6 \times 10^{14}\,s^{-1}$.
All the photons are absorbed in the surface and no photoelectrons are emitted.

Calculate the force exerted on the metal surface by the incident photons.

force = ... N [3]

[Total: 11]

343. 9702_w19_qp_41 Q: 11

(a) With reference to the photoelectric effect, state what is meant by *work function energy*.

....

....

.... [2]

(b) The work function energy of a clean metal surface is 5.5×10^{-19} J.

Electromagnetic radiation of wavelength 280 nm is incident on the metal surface. The metal is in a vacuum.

(i) Calculate:

1. the photon energy

photon energy = ... J [2]

2. the maximum speed v_{MAX} of the electrons emitted from the surface.

v_{MAX} = ... m s^{-1} [3]

(ii) Explain why most of the emitted electrons will have a speed lower than v_{MAX}.

....

.... [1]

(c) The electromagnetic radiation incident on the metal surface may change in intensity or in frequency.

Complete Fig. 11.1 by inserting either '*increases*' or '*decreases*' or '*no change*' to describe the effects of the changes shown on the maximum speed and on the rate of emission of electrons.

change	maximum speed of electrons	rate of emission of electrons
reduced intensity at constant frequency	....	....
increased frequency at constant intensity	....	....

Fig. 11.1

[4]

[Total: 12]

344. 9702_w19_qp_43 Q: 11

(a) With reference to the photoelectric effect, state what is meant by *work function energy*.

....

....

.... [2]

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Electromagnetic radiation of wavelength 280 nm is incident on the metal surface. The metal is in a vacuum.

(i) Calculate:

1. the photon energy

photon energy = ... J [2]

2. the maximum speed v_{MAX} of the electrons emitted from the surface.

v_{MAX} = ... m s^{-1} [3]

(ii) Explain why most of the emitted electrons will have a speed lower than v_{MAX}.

....

.... [1]

(c) The electromagnetic radiation incident on the metal surface may change in intensity or in frequency.

Complete Fig. 11.1 by inserting either '*increases*' or '*decreases*' or '*no change*' to describe the effects of the changes shown on the maximum speed and on the rate of emission of electrons.

change	maximum speed of electrons	rate of emission of electrons
reduced intensity at constant frequency	....	....
increased frequency at constant intensity	....	....

Fig. 11.1

[4]

[Total: 12]

345. 9702_s18_qp_42 Q: 10

(a) Describe the *photoelectric effect*.

....

....

....[2]

(b) Data for the work function energy Φ of two metals are shown in Fig. 10.1.

	Φ / J
sodium	3.8×10^{-19}
zinc	5.8×10^{-19}

Fig. 10.1

Light of wavelength 420 nm is incident on the surface of each of the metals.

(i) State what is meant by a *photon*.

....

....

....[2]

(ii) Calculate the energy of a photon of the incident light.

energy = ... J [2]

(iii) State whether photoelectric emission will occur from each of the metals.

sodium: ....

zinc: ....

[1]

[Total: 7]

346. 9702_m17_qp_42 Q: 10

(a) State what is meant by a *photon*.

....

....[2]

(b) Light in a beam has a continuous spectrum that lies within the visible region. The photons of light have energies ranging from 1.60 eV to 2.60 eV.

The beam passes through some hydrogen gas. It then passes through a diffraction grating and an absorption spectrum is observed.

(i) All of the light absorbed by the hydrogen is re-emitted. Explain why dark lines are still observed in the absorption spectrum.

....

....[1]

(ii) Some of the energy levels of an electron in a hydrogen atom are illustrated in Fig. 10.1.

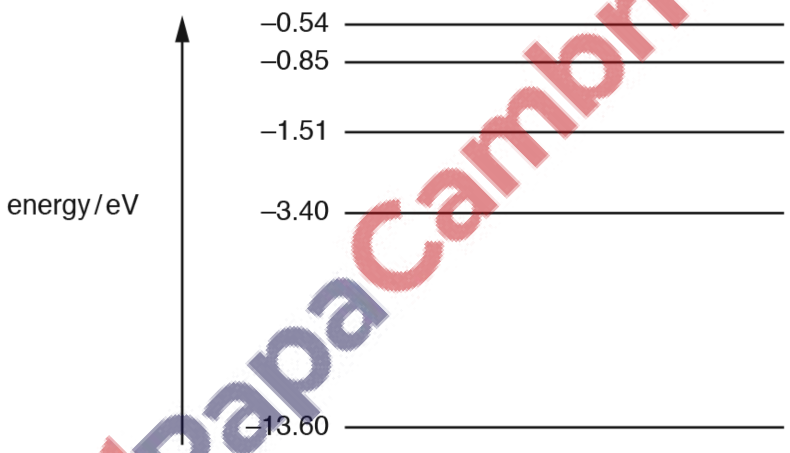

Fig. 10.1 (not to scale)

The dark lines in the absorption spectrum are the result of electron transitions between energy levels.

On Fig. 10.1, draw arrows to show the initial electron transitions between energy levels that could give rise to dark lines in the absorption spectrum. [2]

(iii) Calculate the shortest wavelength of the light in the beam.

wavelength = ... m [3]

[Total: 8]

347. 9702_s17_qp_42 Q: 10

(ii) The variation with $\frac{1}{\lambda}$ of E_{MAX} for the metal surface is shown in Fig. 10.1.

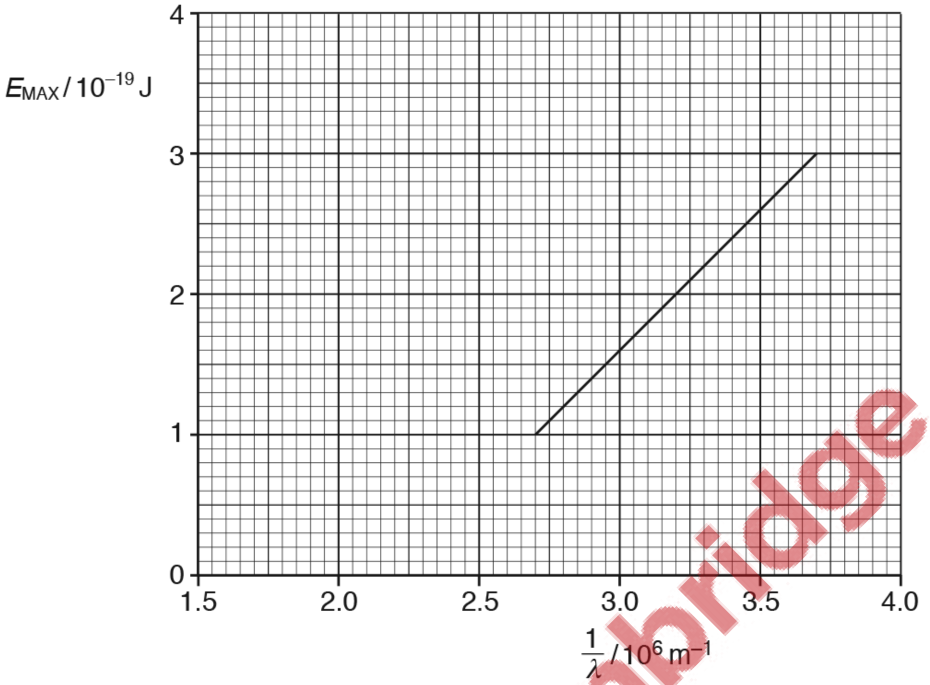

Fig. 10.1

1. Use Fig. 10.1 to determine the magnitude of λ_0.

λ_0 = ... m [1]

2. Use the gradient of Fig. 10.1 to determine a value for the Planck constant *h*.

h = ... J s [3]

(c) The metal surface in **(b)** becomes oxidised.
Photoelectric emission is still observed but the work function energy is increased.

On Fig. 10.1, draw a line to show the variation with $\frac{1}{\lambda}$ of E_{MAX} for the oxidised surface. [2]

[Total: 9]

348. 9702_m16_qp_42 Q: 11

(a) With reference to the photoelectric effect, state what is meant by the *threshold frequency*.

....

....

....[2]

(b) Electromagnetic radiation of wavelength λ is incident on a metal surface. Electrons of maximum kinetic energy E_{MAX} are emitted.

(i) On Fig. 11.1, sketch the variation with $1/\lambda$ of E_{MAX}.

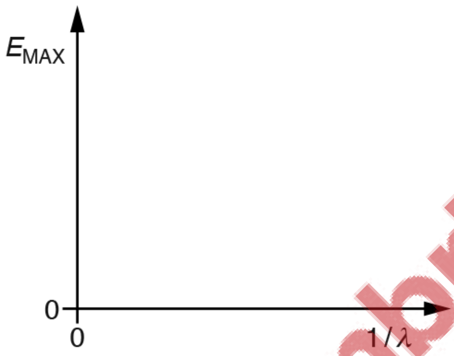

Fig. 11.1

[2]

(ii) State an equation relating the gradient of the graph drawn on Fig. 11.1 to the Planck constant *h*.
Explain any symbols you use.

....

....[1]

(iii) Explain why, for any particular wavelength of electromagnetic radiation, most of the electrons are emitted with kinetic energies less than the maximum value E_{MAX}.

....

....

....

....[2]

(iv) Light of a particular wavelength is incident on a metal surface and gives rise to a photoelectric current.

The wavelength is reduced. The intensity of the light is kept constant.

State and explain the effect, if any, on the photoelectric current.

....

....

....

....

....[3]

[Total: 10]

349. 9702_w16_qp_41 Q: 10

(a) Explain what is meant by the *photoelectric effect*.

....

....

.... [2]

(b) One wavelength of electromagnetic radiation emitted from a mercury vapour lamp is 436 nm.

Calculate the photon energy corresponding to this wavelength.

energy = ... J [2]

(c) Light from the lamp in **(b)** is incident, separately, on the surfaces of caesium and tungsten metal.

Data for the work function energies of caesium and tungsten metal are given in Fig. 10.1.

metal	work function energy / eV
caesium	1.4
tungsten	4.5

Fig. 10.1

Calculate the threshold wavelength for photoelectric emission from

(i) caesium,

threshold wavelength = ... nm [2]

(ii) tungsten.

threshold wavelength = ... nm [1]

(d) Use your answers in **(c)** to state and explain whether the radiation from the mercury lamp of wavelength 436 nm will give rise to photoelectric emission from each of the metals.

caesium: ....

....

tungsten: ....

....

[2]

[Total: 9]

350. 9702_w16_qp_43 Q: 10

(a) Explain what is meant by the *photoelectric effect*.

....

....

.... [2]

(b) One wavelength of electromagnetic radiation emitted from a mercury vapour lamp is 436 nm.

Calculate the photon energy corresponding to this wavelength.

energy = ... J [2]

(c) Light from the lamp in **(b)** is incident, separately, on the surfaces of caesium and tungsten metal.

Data for the work function energies of caesium and tungsten metal are given in Fig. 10.1.

metal	work function energy / eV
caesium	1.4
tungsten	4.5

Fig. 10.1

Calculate the threshold wavelength for photoelectric emission from

(i) caesium,

threshold wavelength = ... nm [2]

(ii) tungsten.

threshold wavelength = ... nm [1]

(d) Use your answers in **(c)** to state and explain whether the radiation from the mercury lamp of wavelength 436 nm will give rise to photoelectric emission from each of the metals.

caesium: ....

....

tungsten: ....

....

[2]

[Total: 9]

351. 9702_s21_qp_42 Q: 11

(a) State the purpose of computed tomography (CT scanning).

....

.... [1]

(b) Outline the principles of CT scanning.

....

....

....

....

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....

....

....

.... [5]

[Total: 6]

352. 9702_s21_qp_42 Q: 12

(a) State what is meant by a *photon*.

....

....

.... [2]

(b) A stationary nucleus of samarium-157 ($^{157}_{62}$Sm) emits a gamma-ray (γ-ray) photon of energy 0.57 MeV.

Determine, for one γ-ray photon:

(i) its wavelength

wavelength = ... m [2]

(ii) its momentum.

momentum = ... N s [2]

(c) **(i)** Using your answer to **(b)(ii)**, determine the speed of the samarium-157 nucleus after emission of the photon.

speed = ... $m\,s^{-1}$ [2]

(ii) By reference to your answer in **(c)(i)**, explain quantitatively why the speed of the samarium-157 nucleus may be assumed to be negligible compared with the speed of the photon.

....

.... [1]

[Total: 9]

353. 9702_w21_qp_41 Q: 10

(a) State an experimental phenomenon that provides evidence for:

(i) the particulate nature of electromagnetic radiation

.... [1]

(ii) the wave nature of matter.

.... [1]

(b) A particle of matter moves with momentum p.

(i) State the equation that gives the effective wavelength λ of the particle. State the name of any other symbols used.

[2]

(ii) State the name given to the wavelength of the moving particle.

.... [1]

(c) Electrons are accelerated from rest through a potential difference (p.d.) of 4.8 kV.

(i) Show that the final speed of the electrons is $4.1 \times 10^{7}\,\mathrm{m\,s^{-1}}$.

[2]

(ii) Calculate the effective wavelength of a beam of electrons moving at the speed in **(c)(i)**.

wavelength = ... m [2]

[Total: 9]

354. 9702_w21_qp_43 Q: 10

(a) State an experimental phenomenon that provides evidence for:

(i) the particulate nature of electromagnetic radiation

.... [1]

(ii) the wave nature of matter.

.... [1]

(b) A particle of matter moves with momentum *p*.

(i) State the equation that gives the effective wavelength λ of the particle. State the name of any other symbols used.

[2]

(ii) State the name given to the wavelength of the moving particle.

.... [1]

(c) Electrons are accelerated from rest through a potential difference (p.d.) of 4.8 kV.

(i) Show that the final speed of the electrons is $4.1 \times 10^7\,\text{m}\,\text{s}^{-1}$.

[2]

(ii) Calculate the effective wavelength of a beam of electrons moving at the speed in **(c)(i)**.

wavelength = ... m [2]

[Total: 9]

355. 9702_s19_qp_41 Q: 11

(a) State **three** pieces of evidence provided by the photoelectric effect for a particulate nature of electromagnetic radiation.

1. ....

....

2. ....

....

3. ....

.... [3]

(b) The work function energies of some metals are shown in Fig. 11.1.

	work function energy / eV
sodium	2.4
calcium	2.9
zinc	3.6
silver	4.3

Fig. 11.1

Each metal is irradiated with electromagnetic radiation of wavelength 380 nm.

(i) Calculate the energy, in eV, of a photon of electromagnetic radiation of wavelength 380 nm.

energy = ...eV [3]

(ii) Determine which metals will give rise to the emission of photoelectrons. Explain your answer.

....

.... [2]

(c) Photons of wavelength 380 nm are incident normally on a metal surface at a rate of $7.6 \times 10^{14}\,s^{-1}$.
All the photons are absorbed in the surface and no photoelectrons are emitted.

Calculate the force exerted on the metal surface by the incident photons.

force = ... N [3]

[Total: 11]

356. 9702_s19_qp_42 Q: 11

(a) State what is meant by a *photon*.

....

....

....[2]

(b) A stationary cobalt-60 ($^{60}_{27}$Co) nucleus emits a γ-ray photon of energy 1.18 MeV.

(i) Calculate the wavelength of the photon.

wavelength = ... m [2]

(ii) Show that the momentum of the photon is 6.3×10^{-22} N s.

[2]

(c) Use information in **(b)(ii)** to determine the recoil speed of the cobalt-60 nucleus when the γ-ray photon is emitted.

speed = ... m s^{-1} [2]

[Total: 8]

357. 9702_w17_qp_41 Q: 11

(a) State what is meant by a *photon*.

....

.... [1]

(b) Indium-123 ($^{123}_{49}In$) is radioactive.
A nucleus of indium-123 emits a γ-ray photon of energy 1.1 MeV.

Determine, for this γ-radiation,

(i) the frequency,

frequency = ... Hz [2]

(ii) the momentum of a photon.

momentum = ... N s [2]

(c) The indium-123 nucleus is stationary before emission of the γ-ray photon.
Use your answer in **(b)(ii)** to estimate the recoil speed of the nucleus after emission of the photon.

speed = ... m s^{-1} [2]

[Total: 7]

358. 9702_w17_qp_42 Q: 10

(a) A metal surface is illuminated with light of a single wavelength λ.
On Fig. 10.1, sketch the variation with λ of the maximum kinetic energy E_{MAX} of the electrons emitted from the surface.
On your graph mark, with the symbol λ_0, the threshold wavelength.

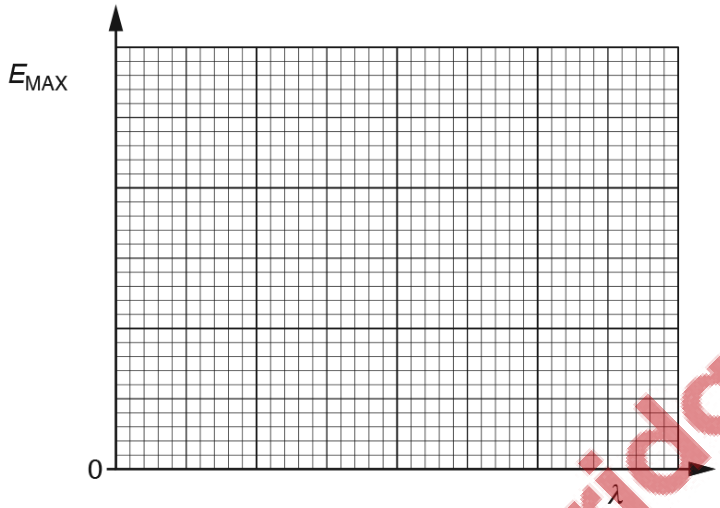

Fig. 10.1 [3]

(b) A neutron is moving in a straight line with momentum p.
The de Broglie wavelength associated with this neutron is λ.
On Fig. 10.2, sketch the variation with momentum p of the de Broglie wavelength λ.

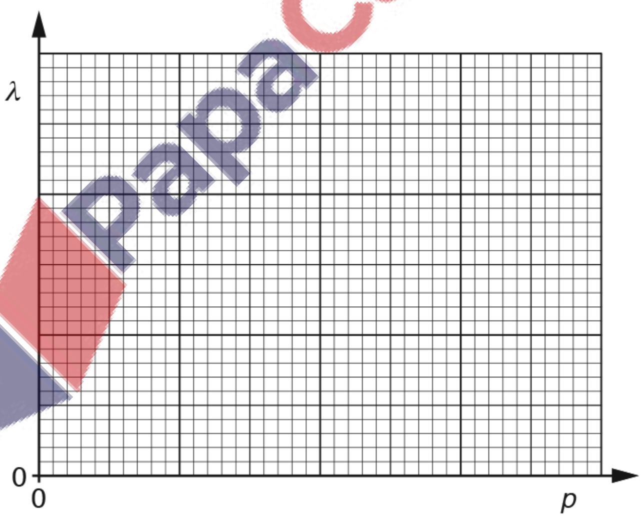

Fig. 10.2 [2]

[Total: 5]

359. 9702_w17_qp_43 Q: 11

(a) State what is meant by a *photon*.

....

.... [1]

(b) Indium-123 ($^{123}_{49}$In) is radioactive.
A nucleus of indium-123 emits a γ-ray photon of energy 1.1 MeV.

Determine, for this γ-radiation,

(i) the frequency,

frequency = ... Hz [2]

(ii) the momentum of a photon.

momentum = ... N s [2]

(c) The indium-123 nucleus is stationary before emission of the γ-ray photon.
Use your answer in **(b)(ii)** to estimate the recoil speed of the nucleus after emission of the photon.

speed = ... m s^{-1} [2]

[Total: 7]

360. 9702_w18_qp_42 Q: 11

(a) State what is meant by a *photon*.

....

....

....[2]

(b) Describe the appearance of a visible line emission spectrum, as seen using a diffraction grating.

....

....

....

....[2]

(c) The lowest electron energy levels in an isolated hydrogen atom are shown in Fig. 11.1.

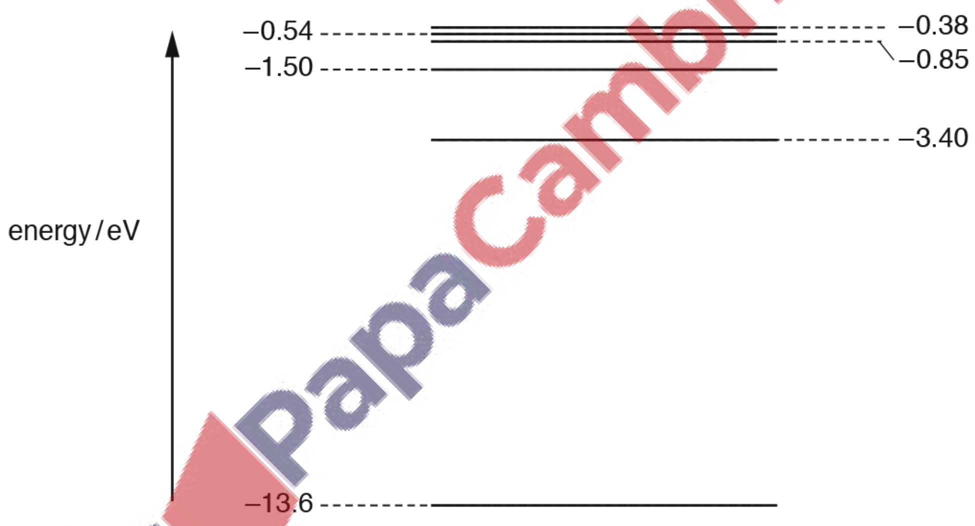

Fig. 11.1 (not to scale)

(i) An electron is initially at the energy level –0.85 eV. State the total number of different wavelengths that may be emitted as the electron de-excites (loses energy).

number = ... [1]

(ii) Photons resulting from electron de-excitation from the −0.85 eV energy level are incident on the surface of a sample of platinum.

Platinum has a work function energy of 5.6 eV.

Determine

1. the maximum kinetic energy, in eV, of a photoelectron emitted from the surface of the platinum,

maximum energy = ... eV [2]

2. the wavelength of the photon producing the photoelectron in **(ii) part 1**.

wavelength = ... m [3]

[Total: 10]

361. 9702_s17_qp_41 Q: 11

A beam of light consists of a continuous range of wavelengths from 420 nm to 740 nm. The light passes through a cloud of cool gas, as shown in Fig. 11.1.

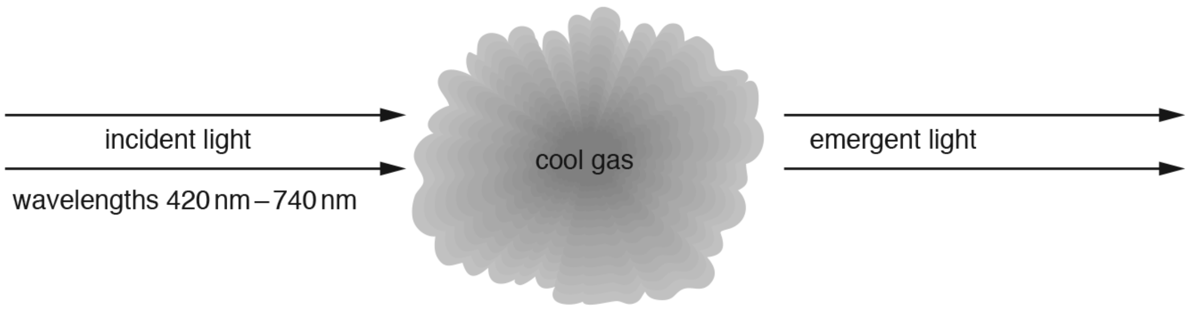

Fig. 11.1

(a) The spectrum of the light emerging from the cloud of cool gas is viewed using a diffraction grating.
Explain why this spectrum contains a number of dark lines.

....

....

....

....

....

.... [4]

(b) Some of the electron energy levels of the atoms in the cloud of gas are represented in Fig. 11.2.

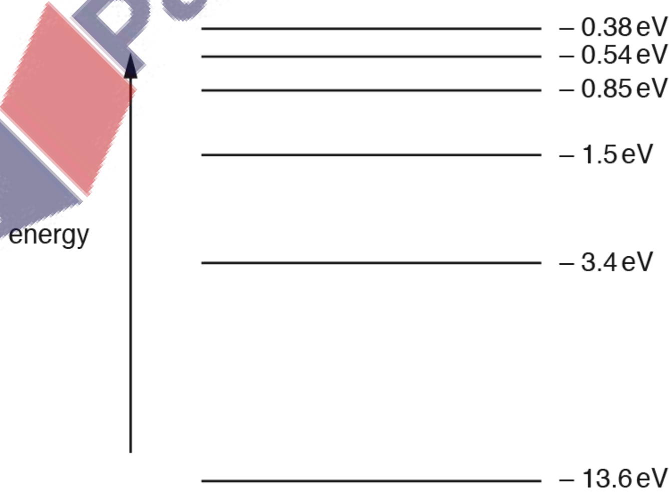

Fig. 11.2 (not to scale)

(i) Light of wavelength 420 nm has a photon energy of 2.96 eV.
Calculate the photon energy, in eV, of light of wavelength 740 nm.

photon energy = ... eV [2]

(ii) Use data from **(i)** and your answer in **(i)** to show, on Fig. 11.2, the changes in energy levels giving rise to the dark lines in **(a)**. [2]

[Total: 8]

362. 9702_s17_qp_42 Q: 11

An electron has charge $-q$ and mass m. It is accelerated from rest in a vacuum through a potential difference V.

(a) Show that the momentum p of the accelerated electron is given by

$$p = \sqrt{(2mqV)}.$$

[2]

(b) The potential difference V through which the electron is accelerated is 120 V.

(i) State what is meant by the *de Broglie wavelength*.

....

....

.... [2]

(ii) Calculate the de Broglie wavelength of the electron.

wavelength = ... m [3]

(c) The separation of copper atoms in a copper crystal is approximately 2×10^{-10} m.

By reference to your answer in **(b)(ii)**, suggest whether electron diffraction could be observed using a beam of electrons that have been accelerated through a potential difference of 120 V and are then incident on a thin copper crystal.

....

....

.... [2]

[Total: 9]

363. 9702_s17_qp_43 Q: 11

A beam of light consists of a continuous range of wavelengths from 420 nm to 740 nm.
The light passes through a cloud of cool gas, as shown in Fig. 11.1.

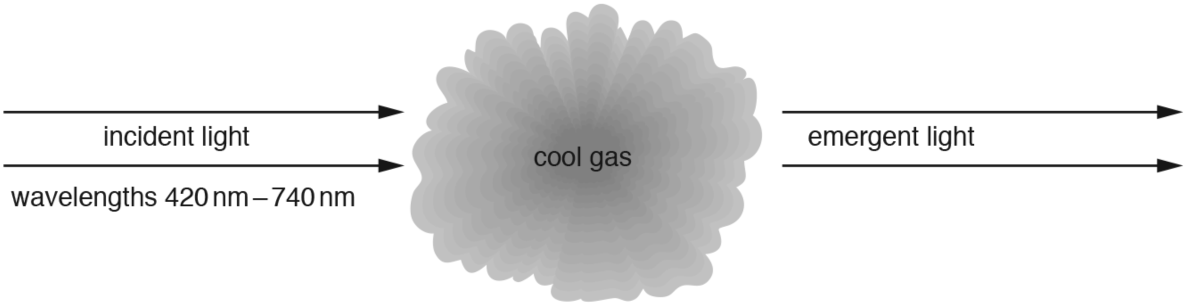

Fig. 11.1

(a) The spectrum of the light emerging from the cloud of cool gas is viewed using a diffraction grating.
Explain why this spectrum contains a number of dark lines.

....

....

....

....

....

.... [4]

(b) Some of the electron energy levels of the atoms in the cloud of gas are represented in Fig. 11.2.

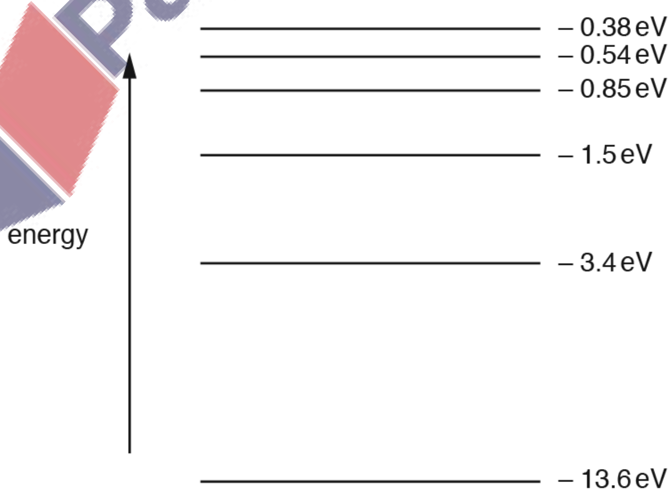

Fig. 11.2 (not to scale)

(i) Light of wavelength 420 nm has a photon energy of 2.96 eV.
Calculate the photon energy, in eV, of light of wavelength 740 nm.

photon energy = ... eV [2]

(ii) Use data from **(i)** and your answer in **(i)** to show, on Fig. 11.2, the changes in energy levels giving rise to the dark lines in **(a)**. [2]

[Total: 8]

364. 9702_w16_qp_42 Q: 12

(a) State an effect, one in each case, that provides evidence for

(i) the wave nature of a particle,

....[1]

(ii) the particulate nature of electromagnetic radiation.

....[1]

(b) Four electron energy levels in an isolated atom are shown in Fig. 12.1.

Fig. 12.1

For the emission spectrum associated with these energy levels,

(i) on Fig. 12.1, mark with an arrow the transition that gives rise to the shortest wavelength, [1]

(ii) show that the wavelength of the transition in **(i)** is 4.35×10^{-7} m.

[2]

(c) **(i)** State what is meant by the *de Broglie wavelength*.

....

....

....[2]

(ii) Calculate the speed of an electron having a de Broglie wavelength equal to the wavelength in **(b)(ii)**.

speed = ... $m s^{-1}$ [2]

[Total: 9]

365. 9702_s20_qp_41 Q: 10

(a) White light passes through a cloud of cool low-pressure gas, as illustrated in Fig. 10.1.

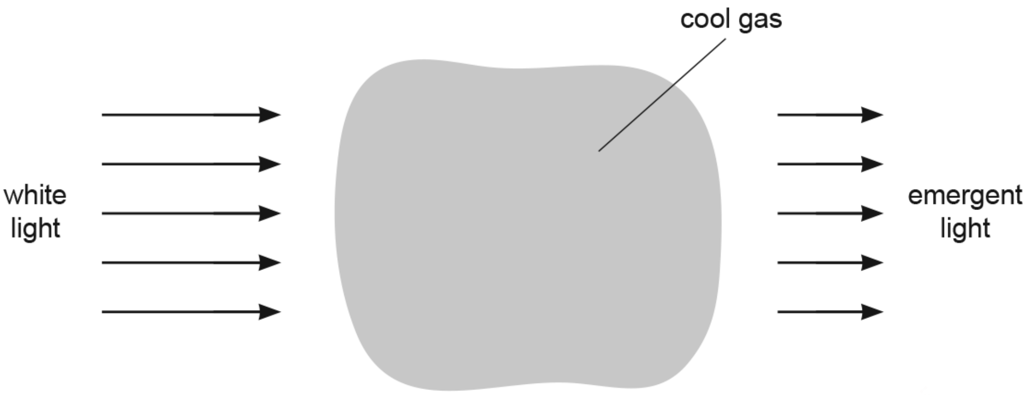

Fig. 10.1

For light that has passed through the gas, its continuous spectrum is seen to contain a number of darker lines.

Use the concept of discrete electron energy levels to explain the existence of these darker lines.

....

....

....

....

....

.... [4]

(b) The uppermost electron energy bands in a solid are illustrated in Fig. 10.2.

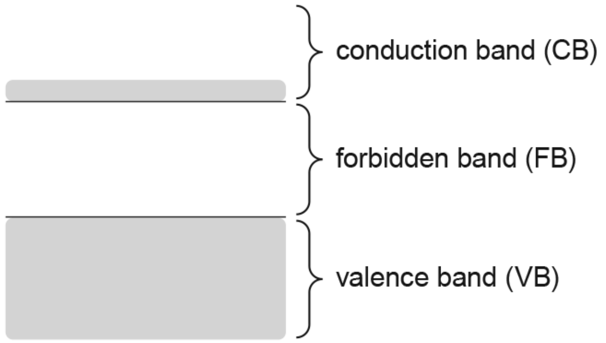

Fig. 10.2

Use band theory to explain the dependence on light intensity of the resistance of a light-dependent resistor (LDR).

....

....

....

....

....

....

.... [5]

[Total: 9]

366. 9702_s20_qp_42 Q: 11

(a) The uppermost energy bands in a solid are known as the valence band (VB), the forbidden band (FB) and the conduction band (CB).

A copper wire is at room temperature.

Use band theory to explain why the resistance of the copper wire increases as its temperature increases.

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.... [4]

(b) The structure of a copper crystal is to be examined using electron diffraction.

Electrons, having been accelerated from rest through a potential difference V, are incident on the crystal.

The de Broglie wavelength λ of the electrons is 2.6×10^{-11} m.

Calculate the accelerating potential difference V.

V = ... V [4]

[Total: 8]

367. 9702_s20_qp_43 Q: 10

(a) White light passes through a cloud of cool low-pressure gas, as illustrated in Fig. 10.1.

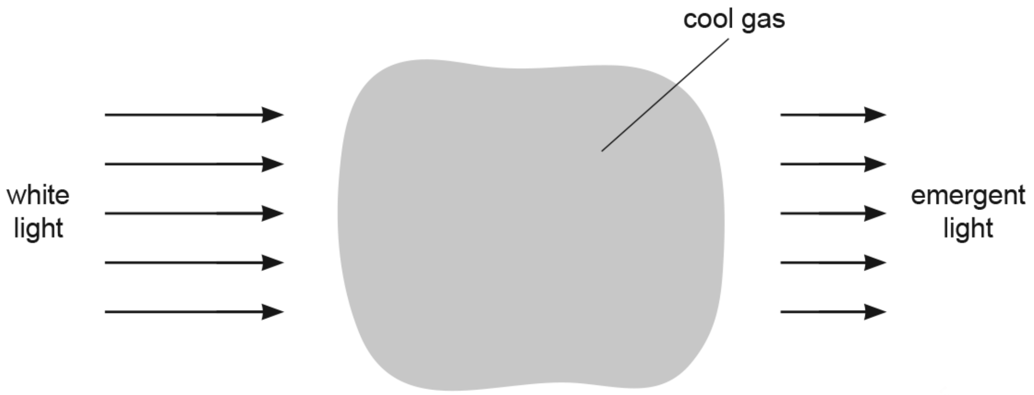

Fig. 10.1

For light that has passed through the gas, its continuous spectrum is seen to contain a number of darker lines.

Use the concept of discrete electron energy levels to explain the existence of these darker lines.

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.... [4]

(b) The uppermost electron energy bands in a solid are illustrated in Fig. 10.2.

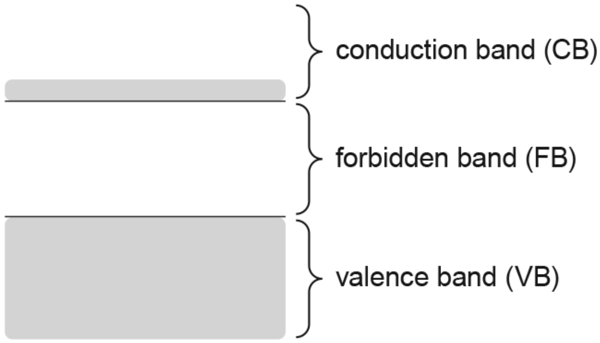

Fig. 10.2

Use band theory to explain the dependence on light intensity of the resistance of a light-dependent resistor (LDR).

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.... [5]

[Total: 9]

368. 9702_m19_qp_42 Q: 11

(a) State what is meant by a *photon*.

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....

.... [2]

(b) Calculate the energy, in eV, of a photon of light of wavelength 540 nm.

energy = ... eV [3]

(c) The outermost electron energy bands of a semiconductor material are illustrated in Fig. 11.1.

Fig. 11.1

The width of the forbidden band is 1.1 eV.

Explain why, when photons of light, each of energy 2.1 eV, are incident on the semiconductor material, its resistance decreases.

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.... [4]

[Total: 9]

369. 9702_w19_qp_42 Q: 10

(a) The upper electron energy bands in an intrinsic semiconductor material are illustrated in Fig. 10.1.

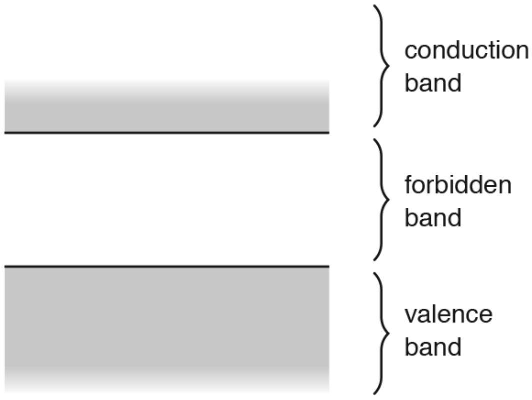

Fig. 10.1

Use band theory to explain why the resistance of an intrinsic semiconductor material decreases as its temperature increases.

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.... [4]

(b) A comparator circuit incorporating an ideal operational amplifier (op-amp) is shown in Fig. 10.2.

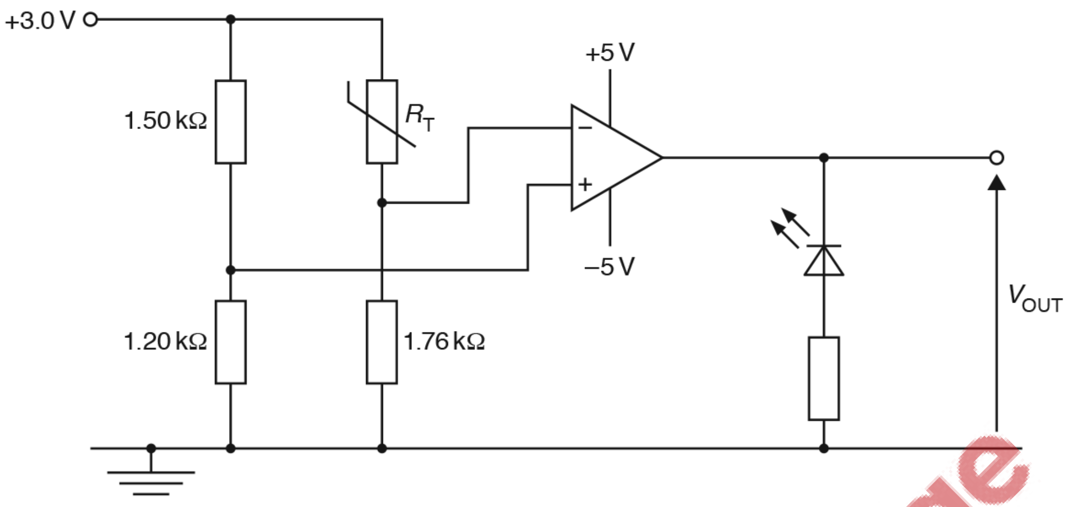

Fig. 10.2

The variation with temperature θ of the resistance R_T of the thermistor is shown in Fig. 10.3.

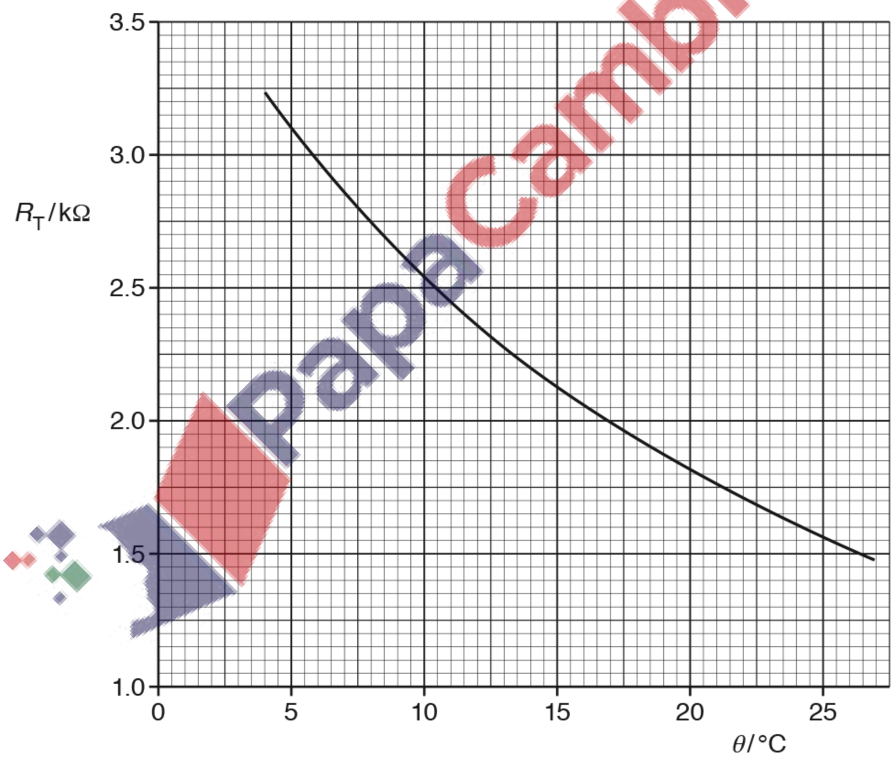

Fig. 10.3

(i) Determine the temperature at which the light-emitting diode (LED) in Fig. 10.2 switches on or off.

temperature = ... °C [4]

(ii) State and explain whether the thermistor is above or below the temperature calculated in **(i)** for the LED to emit light.

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.... [3]

[Total: 11]

370. 9702_m18_qp_42 Q: 11

Some electron energy bands in a solid are shown in Fig. 11.1.

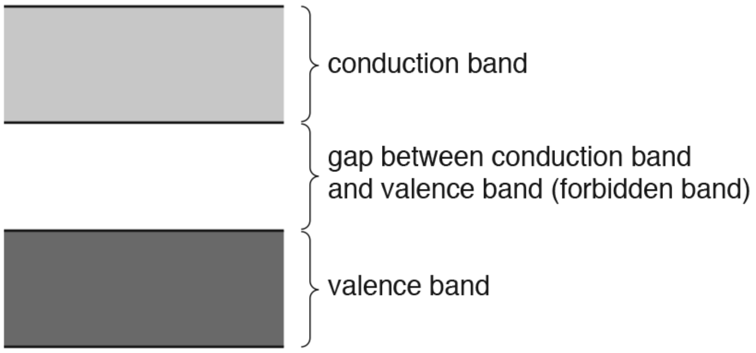

Fig. 11.1

The width of the forbidden band and the number density of charge carriers occupying each band depends on the nature of the solid.

Use band theory to explain why

(a) the resistance of a metal at room temperature increases gradually with temperature,

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....[3]

(b) the resistance, at constant temperature, of a light-dependent resistor (LDR) decreases with increasing light intensity.

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....[4]

[Total: 7]

371. 9702_s18_qp_41 Q: 11

(a) **(i)** Explain what is meant by a *photon*.

....

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....[2]

(ii) By reference to intensity of light, state one piece of evidence provided by the photoelectric effect for a particulate nature of light.

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....[1]

(b) Some electron energy levels in a solid are illustrated in Fig. 11.1.

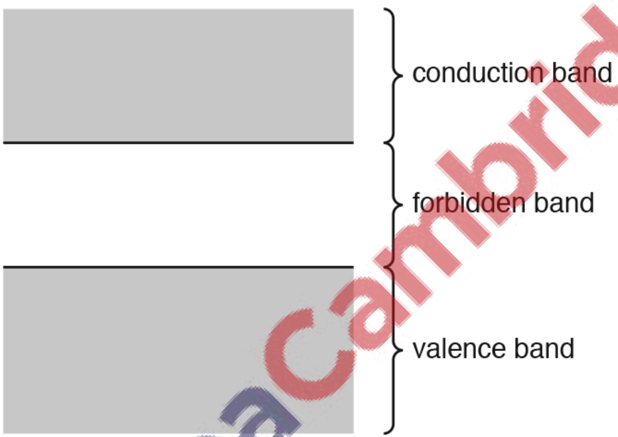

Fig. 11.1

A semiconductor material has a very high resistance in darkness.
Light incident on the semiconductor material causes its resistance to decrease.

Explain the resistance of the semiconductor material in different light conditions.

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....[5]

[Total: 8]

372. 9702_s18_qp_43 Q: 11

(a) **(i)** Explain what is meant by a *photon*.

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....[2]

(ii) By reference to intensity of light, state one piece of evidence provided by the photoelectric effect for a particulate nature of light.

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....[1]

(b) Some electron energy levels in a solid are illustrated in Fig. 11.1.

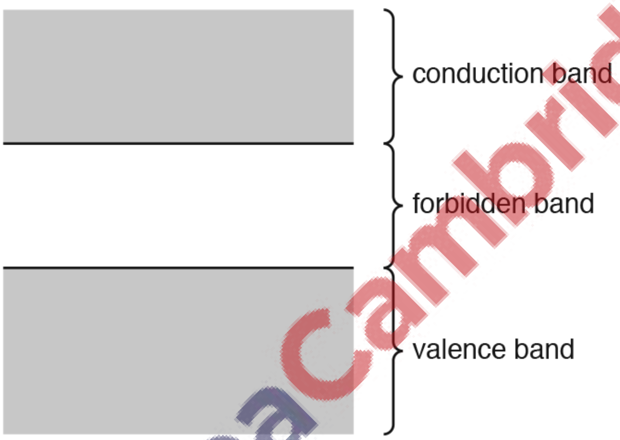

Fig. 11.1

A semiconductor material has a very high resistance in darkness.
Light incident on the semiconductor material causes its resistance to decrease.

Explain the resistance of the semiconductor material in different light conditions.

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....[5]

[Total: 8]

373. 9702_w18_qp_41 Q: 10

Some of the electron energy bands in a semiconductor material at the absolute zero of temperature are shown in Fig. 10.1.

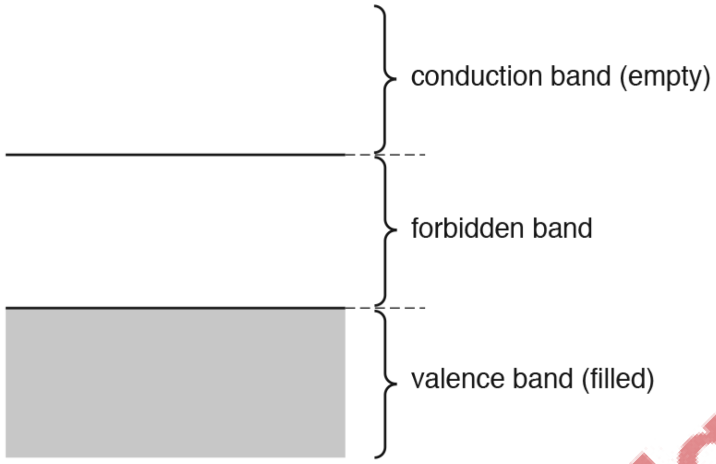

Fig. 10.1

Use band theory to explain why, as the temperature of the semiconductor material rises, the electrical resistance of the sample of material decreases.

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....[5]

374. 9702_w18_qp_43 Q: 10

Some of the electron energy bands in a semiconductor material at the absolute zero of temperature are shown in Fig. 10.1.

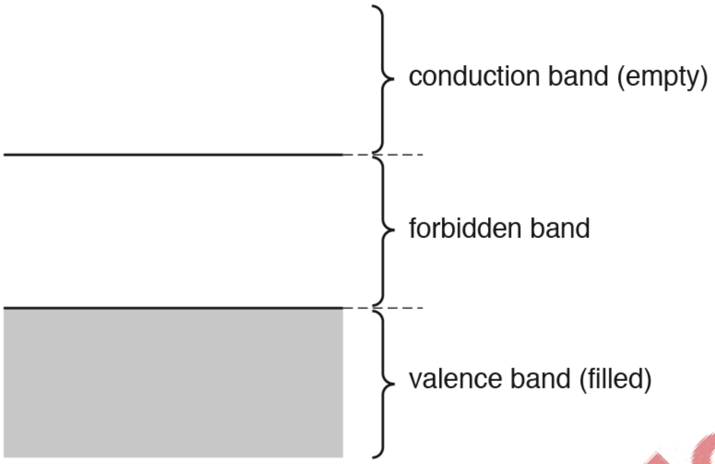

Fig. 10.1

Use band theory to explain why, as the temperature of the semiconductor material rises, the electrical resistance of the sample of material decreases.

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.... [5]

375. 9702_m17_qp_42 Q: 11

Use band theory to explain why, unlike a copper wire, the resistance of an intrinsic semiconductor **decreases** with an increase of temperature.

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....[5]

[Total: 5]

376. 9702_w16_qp_41 Q: 11

Some of the electron energy bands in a solid are illustrated in Fig. 11.1.

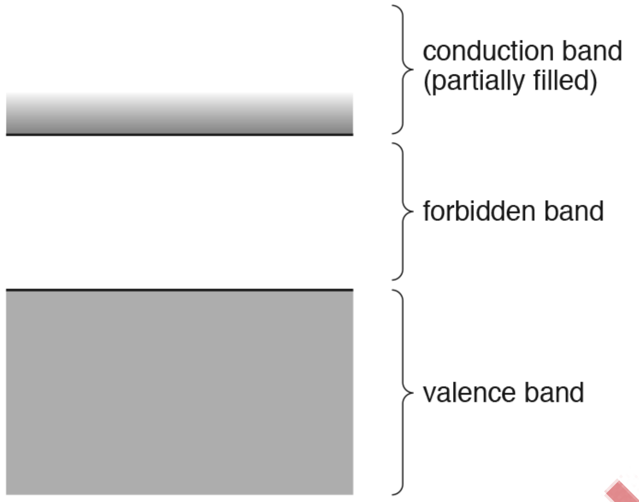

Fig. 11.1

The width of the forbidden band and the number of charge carriers occupying each band depends on the nature of the solid.

Use band theory to explain why the resistance of a sample of a metal at room temperature changes with increasing temperature.

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.... [5]

[Total: 5]

377. 9702_w16_qp_43 Q: 11

Some of the electron energy bands in a solid are illustrated in Fig. 11.1.

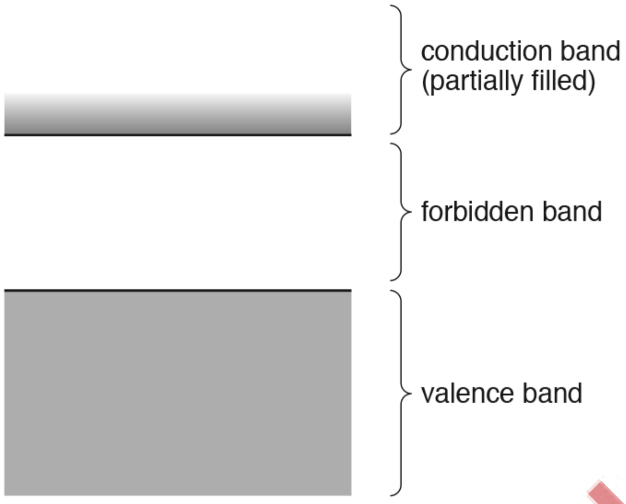

Fig. 11.1

The width of the forbidden band and the number of charge carriers occupying each band depends on the nature of the solid.

Use band theory to explain why the resistance of a sample of a metal at room temperature changes with increasing temperature.

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.... [5]

[Total: 5]

378. 9702_m21_qp_42 Q: 11

(a) Electrons are accelerated through a potential difference of 15 kV. The electrons collide with a metal target and a spectrum of X-rays is produced.

(i) Explain why a continuous spectrum of energies of X-ray photons is produced.

....

....

....

....

.... [3]

(ii) Calculate the wavelength of the highest energy X-ray photon produced.

wavelength = ... m [3]

(b) A beam of X-rays has an initial intensity I_o. The beam is directed into some body tissue. After passing through a thickness *x* of tissue the intensity is I. The graph in Fig. 11.1 shows the variation with *x* of ln (I/I_o).

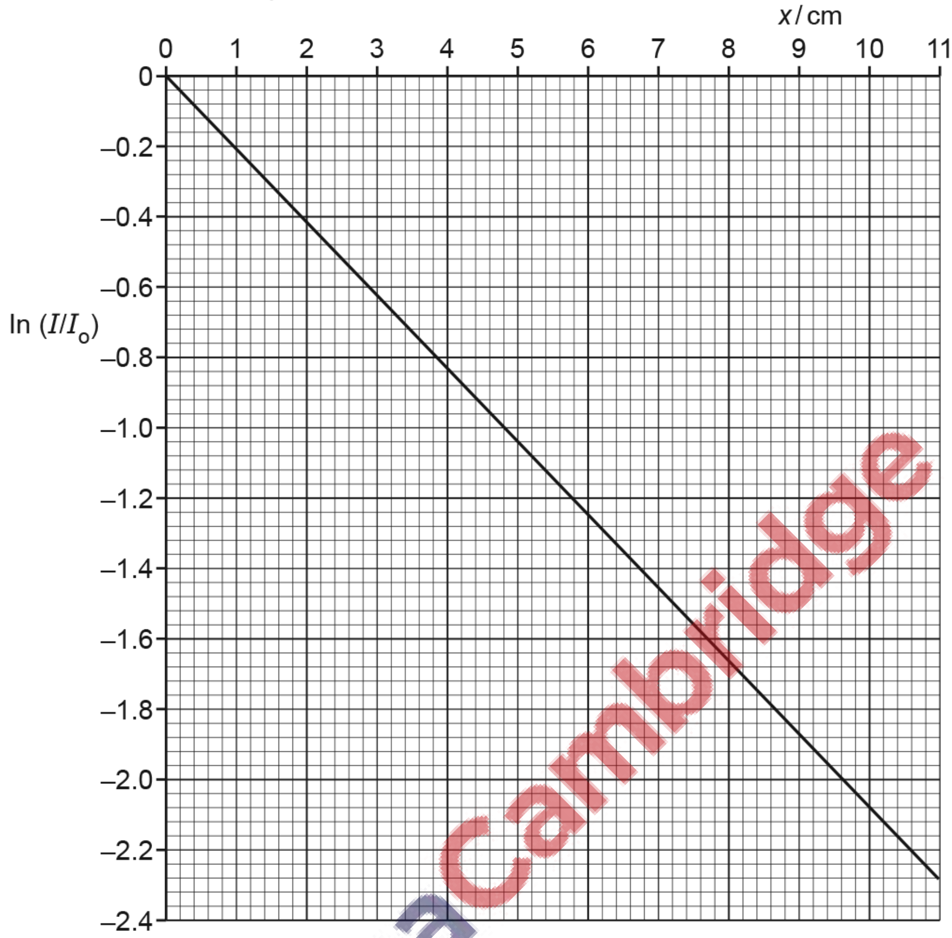

Fig. 11.1

(i) Determine the linear attenuation (absorption) coefficient μ for this beam of X-rays in the tissue.

μ = ... cm^{-1} [2]

(ii) Determine the thickness of tissue that the X-ray beam must pass through so that the intensity of the beam is reduced to 5.0% of its initial value.

thickness = ... cm [2]

[Total: 10]

379. 9702_s21_qp_41 Q: 11

(a) State how, in a modern X-ray tube, the intensity of the X-ray beam and its hardness are controlled.

intensity: ....

....

hardness: ....

.... [2]

(b) A model of a limb consists of soft tissue and bone, as illustrated in Fig. 11.1.

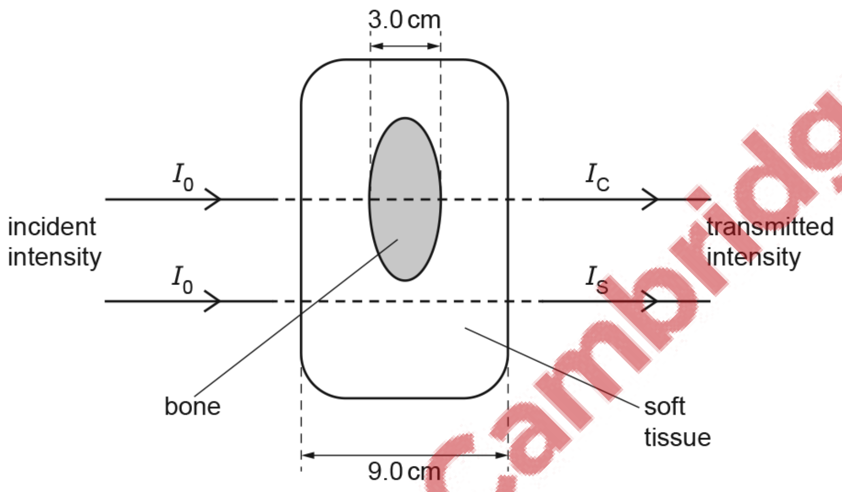

Fig. 11.1

The soft tissue has a thickness of 9.0 cm. The bone within the soft tissue has a thickness of 3.0 cm.

Data for the linear attenuation (absorption) coefficient μ of X-rays in soft tissue and in bone are shown in Table 11.1.

Table 11.1

	μ / cm^{-1}
soft tissue	0.92
bone	2.9

A parallel beam of X-rays of intensity I_0 is incident normally on the model.

Calculate, in terms of I_0:

(i) the transmitted intensity I_S through soft tissue alone

I_S = ... I_0 [2]

(ii) the transmitted intensity I_C through soft tissue and bone.

I_C = ... I_0 [2]

(c) By reference to your answers in **(b)**, suggest, with a reason, whether good contrast on an X-ray image would be obtained.

....

.... [1]

[Total: 7]

380. 9702_s21_qp_43 Q: 11

(a) State how, in a modern X-ray tube, the intensity of the X-ray beam and its hardness are controlled.

intensity: ....

....

hardness: ....

....
[2]

(b) A model of a limb consists of soft tissue and bone, as illustrated in Fig. 11.1.

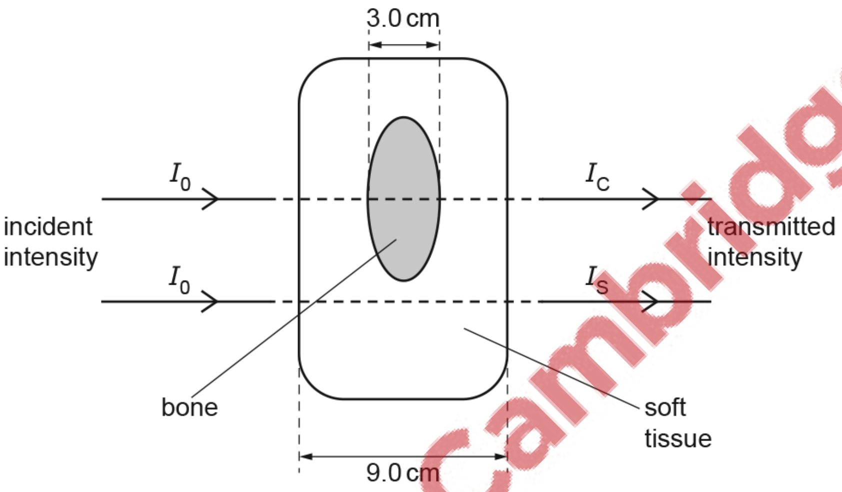

Fig. 11.1

The soft tissue has a thickness of 9.0 cm. The bone within the soft tissue has a thickness of 3.0 cm.

Data for the linear attenuation (absorption) coefficient μ of X-rays in soft tissue and in bone are shown in Table 11.1.

Table 11.1

	μ / cm^{-1}
soft tissue	0.92
bone	2.9

A parallel beam of X-rays of intensity I_0 is incident normally on the model.

Calculate, in terms of I_0:

(i) the transmitted intensity I_S through soft tissue alone

I_S = ... I_0 [2]

(ii) the transmitted intensity I_C through soft tissue and bone.

I_C = ... I_0 [2]

(c) By reference to your answers in **(b)**, suggest, with a reason, whether good contrast on an X-ray image would be obtained.

....

.... [1]

[Total: 7]

381. 9702_w21_qp_41 Q: 11

(a) State, for an X-ray image, what is meant by:

(i) *sharpness*

....

.... [1]

(ii) *contrast*.

....

.... [1]

(b) A parallel X-ray beam passes through a thickness of 2.3 cm of soft body tissue. The intensity of the emerging beam is 12% of the intensity of the incident beam.

Calculate the linear attenuation (absorption) coefficient μ of the soft body tissue. Give a unit with your answer.

μ = ... unit .... [3]

(c) In medical diagnosis, X-rays may be used to produce a single X-ray image or may be used in computed tomography (CT scanning).

Suggest an advantage and a disadvantage of CT scanning compared with single X-ray imaging for diagnosis.

advantage: ....

....

disadvantage: ....

....

[2]

[Total: 7]

382. 9702_w21_qp_43 Q: 11

(a) State, for an X-ray image, what is meant by:

(i) *sharpness*

....

.... [1]

(ii) *contrast*.

....

.... [1]

(b) A parallel X-ray beam passes through a thickness of 2.3 cm of soft body tissue. The intensity of the emerging beam is 12% of the intensity of the incident beam.

Calculate the linear attenuation (absorption) coefficient μ of the soft body tissue. Give a unit with your answer.

μ = ... unit .... [3]

(c) In medical diagnosis, X-rays may be used to produce a single X-ray image or may be used in computed tomography (CT scanning).

Suggest an advantage and a disadvantage of CT scanning compared with single X-ray imaging for diagnosis.

advantage: ....

....

disadvantage: ....

....

[2]

[Total: 7]

383. 9702_m20_qp_42 Q: 11

Electrons are accelerated through a potential difference of 100 kV. They are then incident on a metal target, they decelerate, and X-ray photons are emitted.

(a) Calculate the maximum possible frequency of the emitted X-ray photons.

frequency = ... Hz [2]

(b) Explain why an aluminium filter may be placed in the X-ray beam when producing an X-ray image of a patient.

....

....

....

....

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.... [3]

(c) The linear attenuation (absorption) coefficients μ for X-rays in bone, blood and muscle are given in Table 11.1.

Table 11.1

	μ/cm^{-1}
bone	3.0
blood	0.23
muscle	0.22

(i) A beam of these X-rays is incident on a person.

Calculate the percentage of the intensity of the X-ray beam that has been absorbed after passing through 0.80 cm of blood.

percentage of intensity absorbed = ... % [2]

(ii) In an X-ray image, white regions show greater absorption of X-rays than dark regions.

State and explain the difference between the X-ray image of bone compared to that of muscle.

....

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.... [2]

[Total: 9]

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384. 9702_m19_qp_42 Q: 9

Outline the principles of computed tomography (CT) scanning.

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.... [5]

[Total: 5]

385. 9702_w19_qp_42 Q: 7

Describe the principles of computed tomography (CT) scanning.

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.... [5]

386. 9702_m18_qp_42 Q: 12

(a) Suggest **two** causes of lack of sharpness of an X-ray image.

1. ....

....

2. ....

....[2]

(b) The thickness of a sheet of metal is examined using a parallel X-ray beam, as illustrated in Fig. 12.1.

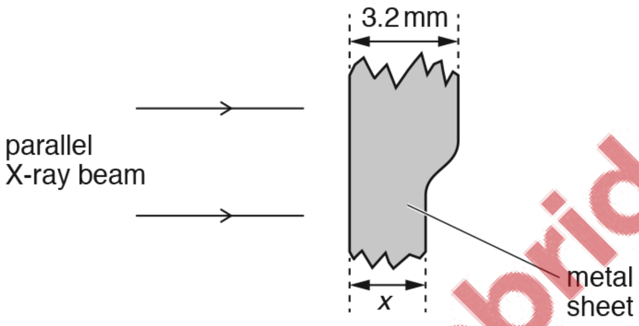

Fig. 12.1 (not to scale)

Part of the beam passes normally through the metal of thickness 3.2 mm. Another part of the beam passes normally through the metal of thickness *x* mm.

The linear attenuation (absorption) coefficient for the X-ray beam in the metal is 1.5 cm^{-1}.

The ratio

$$\frac{\text{intensity of X-ray beam transmitted through 3.2 mm of metal}}{\text{intensity of X-ray beam transmitted through } x \text{ mm of metal}}$$

is found to be 0.81.

(i) Calculate the thickness *x*.

x = ... mm [2]

(ii) The ratio of the intensities is also the ratio of the powers of the X-ray beams.
Calculate this ratio in decibels.

ratio = ... dB [2]

[Total: 6]

387. 9702_s18_qp_41 Q: 12

An X-ray beam is used to produce an image of a model of a thumb.
A parallel beam of X-ray radiation of intensity I_0 is incident on the model, as illustrated in Fig. 12.1.

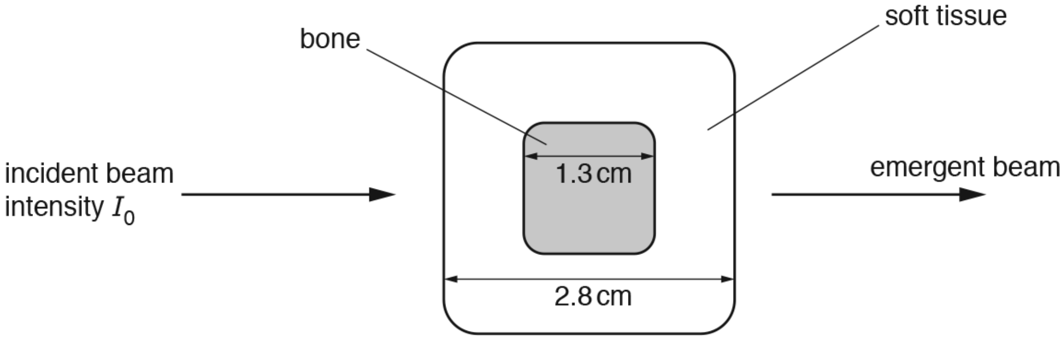

Fig. 12.1

Data for the attenuation (absorption) coefficient μ in bone and in soft tissue are shown in Fig. 12.2.

	μ/cm^{-1}
bone	3.0
soft tissue	0.90

Fig. 12.2

(a) Calculate, in terms of the incident intensity I_0 of the X-ray beam, the intensity of the beam after passing through

(i) a thickness of 2.8 cm of soft tissue,

intensity = ... I_0 [2]

388. 9702_s18_qp_42 Q: 11

(a) Describe the basic principles of CT scanning (computed tomography).

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....[5]

(b) By reference to your answer in **(a)**, suggest why

(i) CT scanning was not possible before fast computers with large memories were available,

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....[1]

(ii) the radiation dose for a CT scan is much larger than for an X-ray image of a leg bone.

....

....

....[1]

[Total: 7]

389. 9702_s18_qp_43 Q: 12

An X-ray beam is used to produce an image of a model of a thumb.
A parallel beam of X-ray radiation of intensity I_0 is incident on the model, as illustrated in Fig. 12.1.

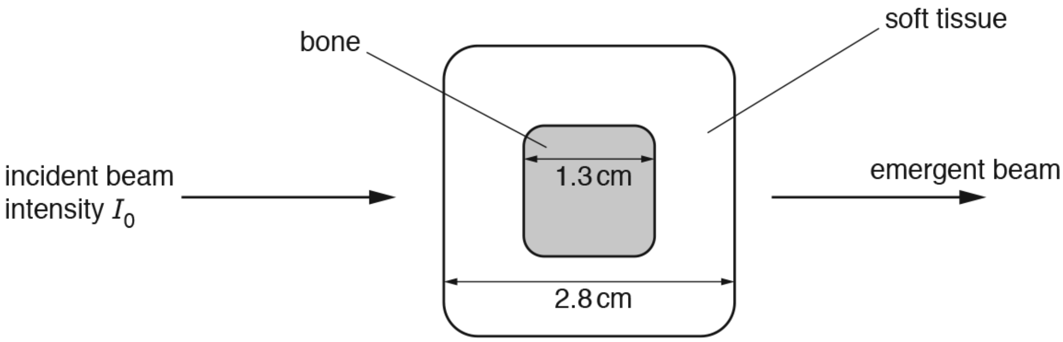

Fig. 12.1

Data for the attenuation (absorption) coefficient μ in bone and in soft tissue are shown in Fig. 12.2.

	μ/cm^{-1}
bone	3.0
soft tissue	0.90

Fig. 12.2

(a) Calculate, in terms of the incident intensity I_0 of the X-ray beam, the intensity of the beam after passing through

(i) a thickness of 2.8 cm of soft tissue,

intensity = ... I_0 [2]

(ii) the bone and soft tissue, as shown in Fig. 12.1.

intensity = ... I_0 [2]

(b) (i) State what is meant by the *contrast* of an X-ray image.

....

....

....[2]

(ii) By reference to your answers in **(a)**, suggest whether the X-ray image of the model has good contrast.

....

....

....[1]

[Total: 7]

390. 9702_w18_qp_42 Q: 10

(a) The root-mean-square (r.m.s.) value of the voltage of a sinusoidal alternating supply is 9.9 V. The frequency of the supply is 50 Hz.

Derive an expression for the variation with time *t* (in second) of the potential difference *V* (in volt) of the supply.

V = ... [2]

(b) Explain the function of the non-uniform magnetic field superposed on the large constant magnetic field in diagnosis using magnetic resonance imaging (NMRI).

....

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....[3]

(c) A parallel beam of X-rays of intensity I_0 is incident normally on some soft tissue and bone, as illustrated in Fig. 10.1.

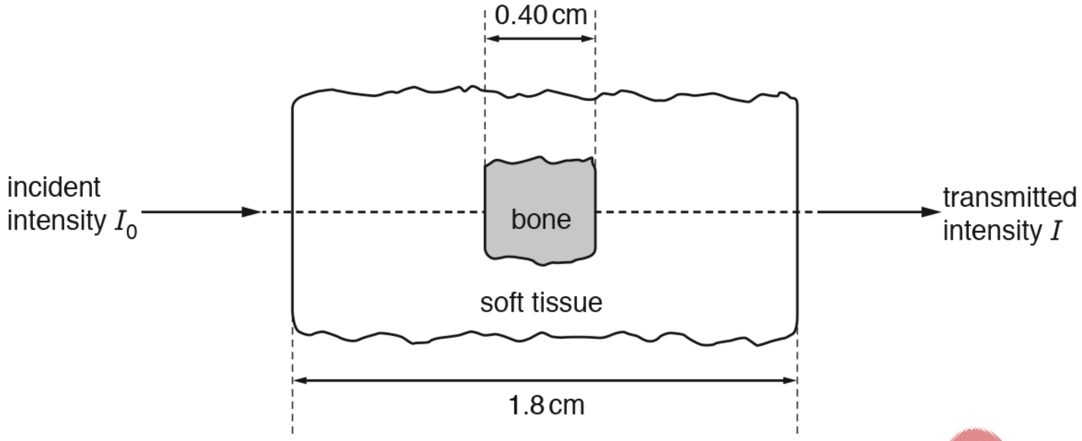

Fig. 10.1

The bone is 0.40 cm thick and the total thickness of the bone and the soft tissue is 1.8 cm. The intensity of the transmitted beam is I.

Data for the linear attenuation (absorption) coefficient μ of bone and of soft tissue are given in Fig. 10.2.

	μ / cm^{-1}
bone	2.9
soft tissue	0.92

Fig. 10.2

Calculate, in dB, the ratio

$$\frac{\text{transmitted intensity } I}{\text{incident intensity } I_0}.$$

ratio = ... dB [4]

[Total: 9]

391. 9702_s17_qp_41 Q: 10

(a) State

(i) what is meant by the *hardness* of an X-ray beam,

....

....

....[2]

(ii) how the hardness of an X-ray beam from an X-ray tube is increased.

....

....[1]

(b) The same parallel beam of X-ray radiation is incident, separately, on samples of bone and of muscle.

Data for the thickness *x* of the samples of bone and of muscle, together with the linear attenuation (absorption) coefficients μ of the radiation in bone and in muscle, are given in Fig. 10.1.

	x / cm	μ / cm^{-1}
bone	1.5	2.9
muscle	4.0	0.95

Fig. 10.1

Determine the ratio

$$\frac{\text{intensity transmitted through bone}}{\text{intensity transmitted through muscle}}.$$

ratio = ... [2]

[Total: 5]

392. 9702_s17_qp_43 Q: 10

(a) State

(i) what is meant by the *hardness* of an X-ray beam,

....

....

....[2]

(ii) how the hardness of an X-ray beam from an X-ray tube is increased.

....

....[1]

(b) The same parallel beam of X-ray radiation is incident, separately, on samples of bone and of muscle.

Data for the thickness x of the samples of bone and of muscle, together with the linear attenuation (absorption) coefficients μ of the radiation in bone and in muscle, are given in Fig. 10.1.

	x / cm	μ / cm^{-1}
bone	1.5	2.9
muscle	4.0	0.95

Fig. 10.1

Determine the ratio

$$\frac{\text{intensity transmitted through bone}}{\text{intensity transmitted through muscle}}.$$

ratio = ... [2]

[Total: 5]

393. 9702_w17_qp_41 Q: 9

(a) In computed tomography (CT scanning), it is necessary to take a series of many X-ray images.
Outline briefly the principles of CT scanning.

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.... [4]

(b) A student creates a model for CT scanning.
A section is divided into four voxels, with pixel numbers A, B, C and D, as shown in Fig. 9.1.

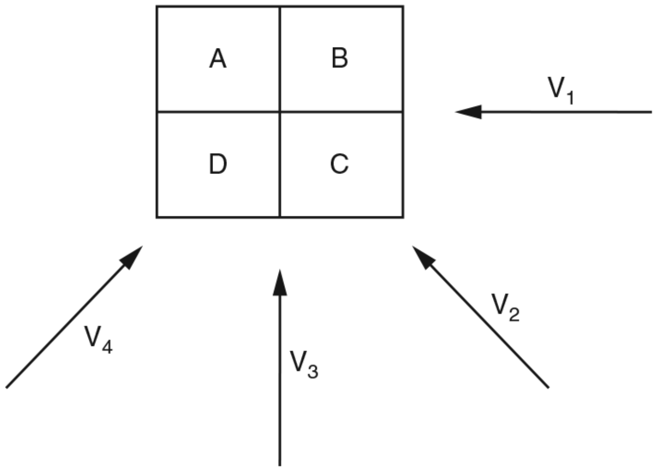

Fig. 9.1

The section is viewed from four different directions V_1, V_2, V_3 and V_4, as shown in Fig. 9.1.

The detector readings for each direction are noted and then summed. The result is shown in Fig. 9.2.

47	59
44	32

Fig. 9.2

The background count is 26.

Determine the pixel numbers A, B, C and D as shown in Fig. 9.1.

A .... B ....

D .... C ....

[3]

[Total: 7]

394. 9702_w17_qp_43 Q: 9

(a) In computed tomography (CT scanning), it is necessary to take a series of many X-ray images.
Outline briefly the principles of CT scanning.

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.... [4]

(b) A student creates a model for CT scanning.
A section is divided into four voxels, with pixel numbers A, B, C and D, as shown in Fig. 9.1.

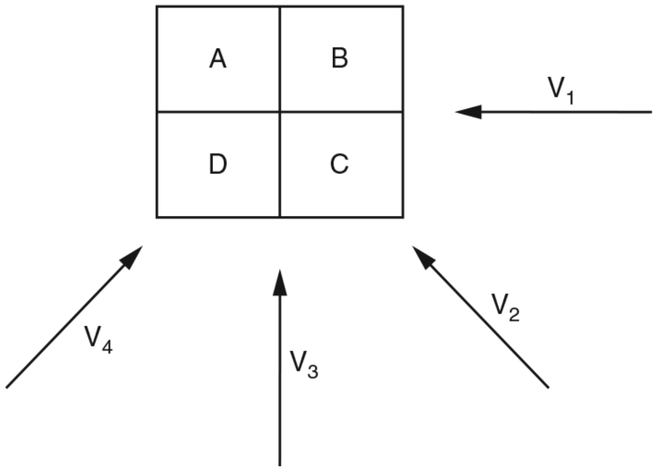

Fig. 9.1

The section is viewed from four different directions V_1, V_2, V_3 and V_4, as shown in Fig. 9.1.

The detector readings for each direction are noted and then summed. The result is shown in Fig. 9.2.

47	59
44	32

Fig. 9.2

The background count is 26.

Determine the pixel numbers A, B, C and D as shown in Fig. 9.1.

A .... B ....

D .... C ....

[3]

[Total: 7]

395. 9702_m16_qp_42 Q: 12

(a) In an X-ray tube, the hardness of an X-ray beam may be controlled.

(i) State what is meant by the *hardness* of the beam.

....

....[1]

(ii) State how the hardness of the beam may be decreased.

....

....[1]

(b) State one advantage and one disadvantage of producing a CT scan image of a person rather than a standard X-ray image.

advantage: ....

....

disadvantage: ....

....

[2]

[Total: 4]

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396. 9702_w16_qp_42 Q: 13

Outline the principles of computed tomography (CT scanning).

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....

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....

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....

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....

....

....[6]

[Total: 6]