CAMBRIDGE INTERNATIONAL AS & A LEVEL PHYSICS · 9702

PHYSICS



EXAM QUESTION PACK

22 QUANTUM PHYSICS

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Chapter 15

Quantum physics

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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

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

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(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.

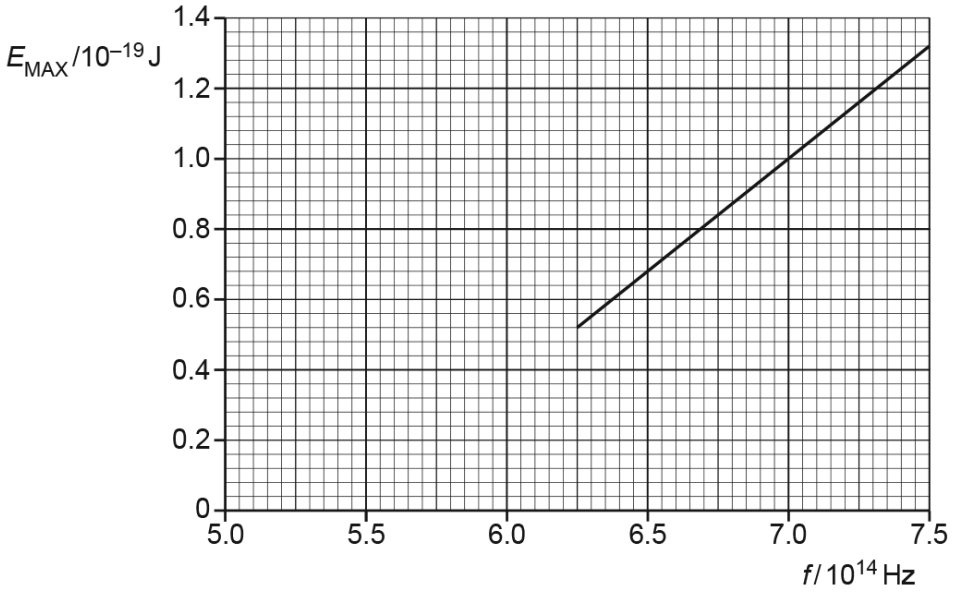


Fig. 10.1

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

work function energy = ... J [2]

24

(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]

(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]

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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.

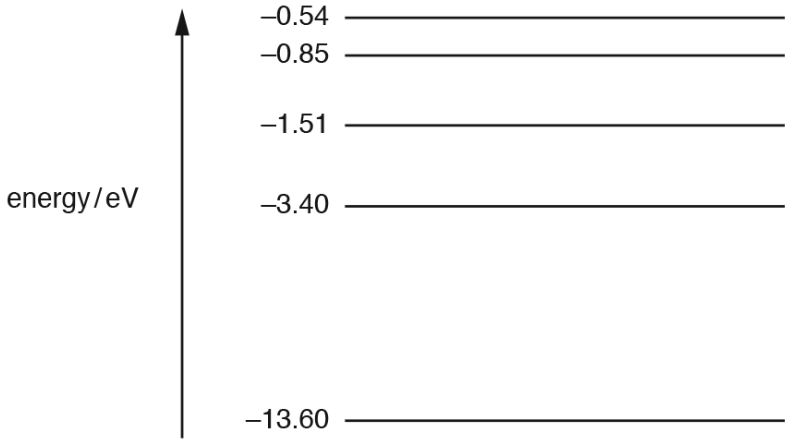


Fig. 10.1 (not to scale)

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]

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

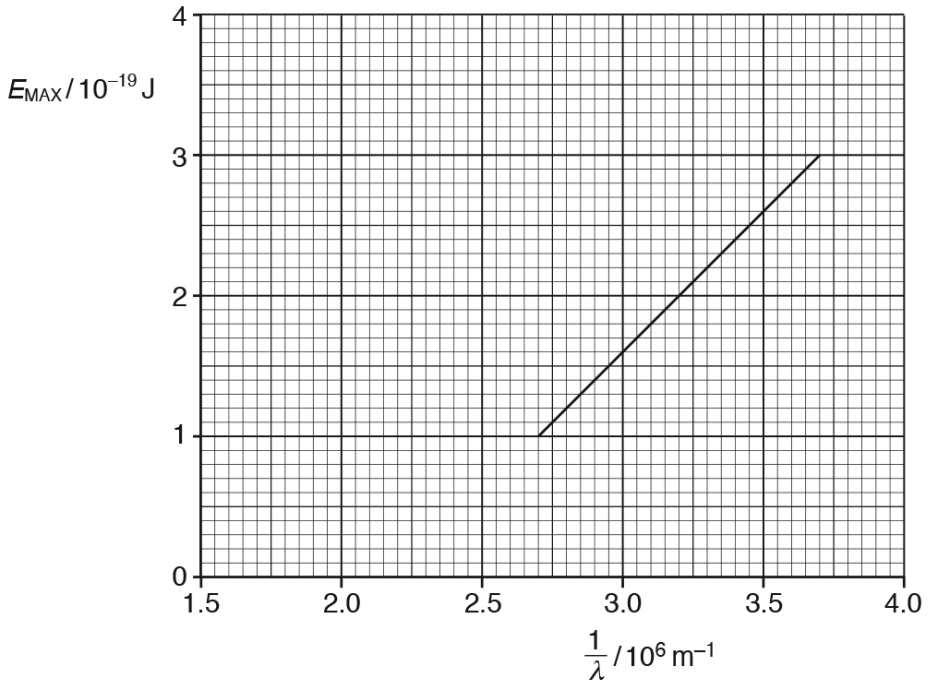


Fig. 10.1

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}.

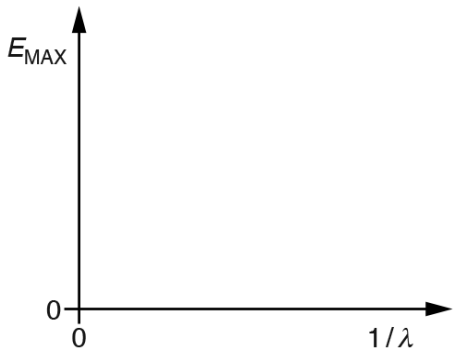


Fig. 11.1

[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]

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(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.

.....

.....

.....

.....

.....

.....

.....

.....

.....

..... [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 $4.1 \times 10^7\,\text{m s}^{-1}$.

[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 $4.1 \times 10^7\,\text{m s}^{-1}$.

[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.

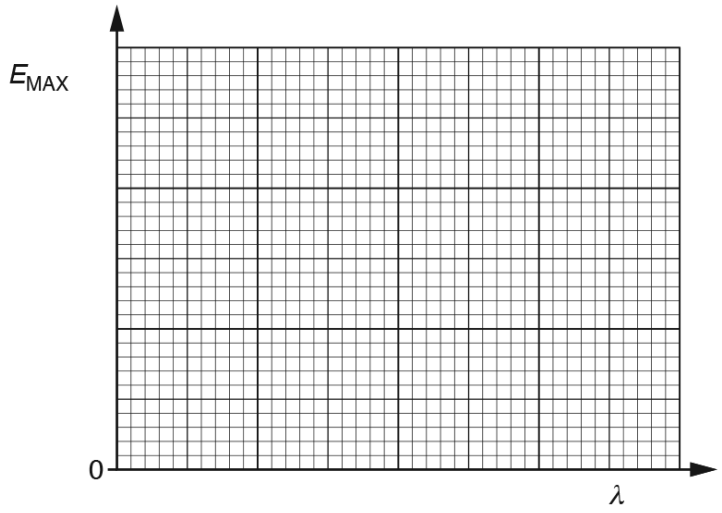


Fig. 10.1 [3]

(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.

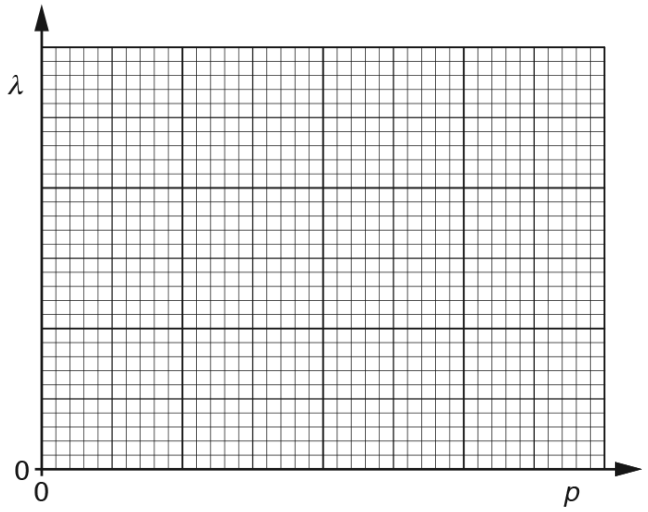


Fig. 10.2 [2]

[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.

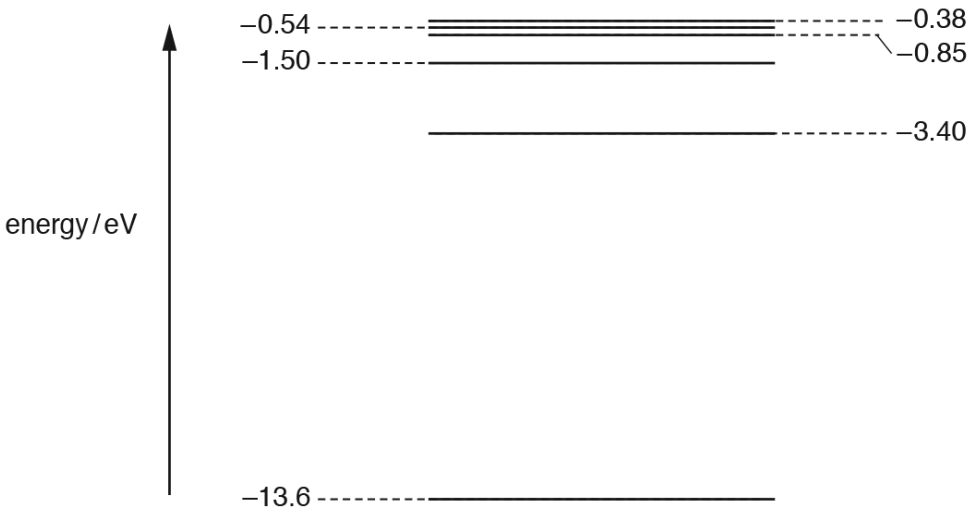


Fig. 11.1 (not to scale)

(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.

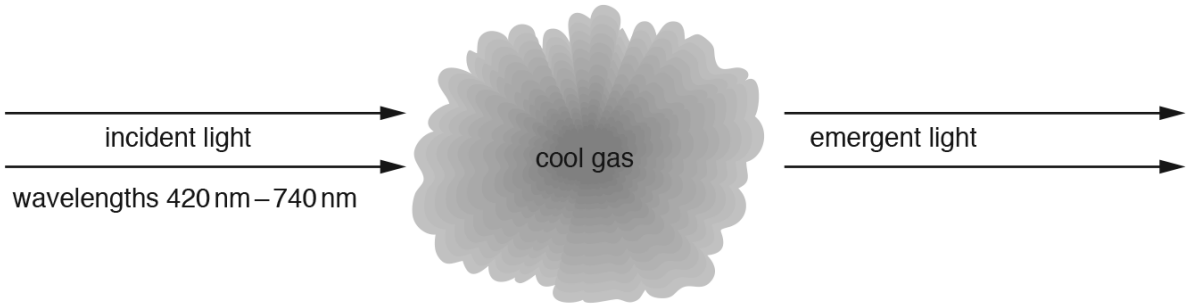


Fig. 11.1

(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.

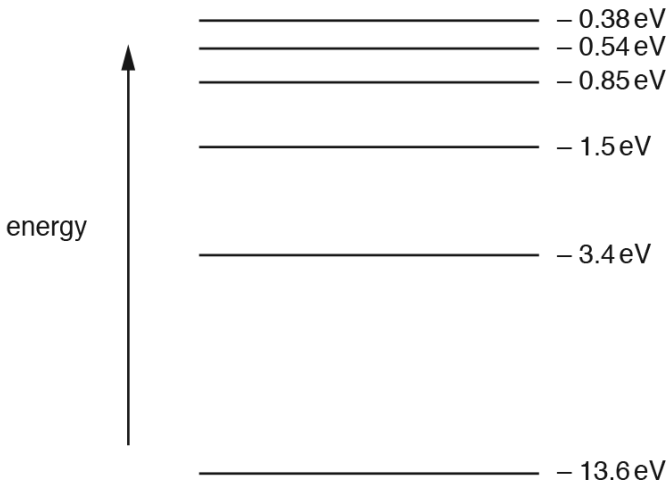


Fig. 11.2 (not to scale)

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(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.

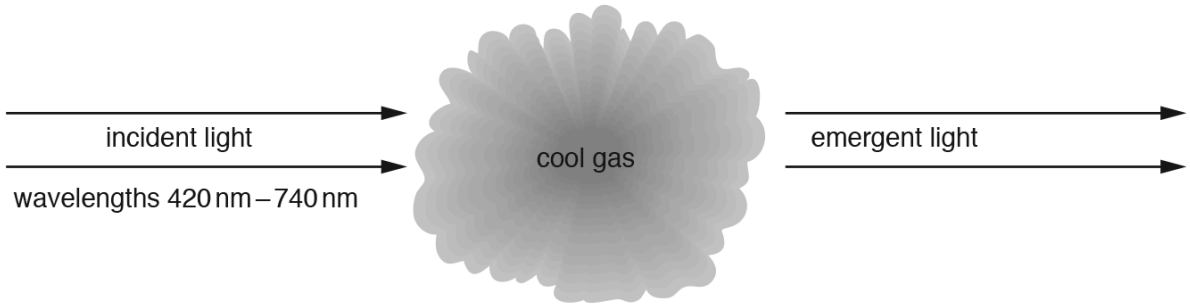


Fig. 11.1

(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.

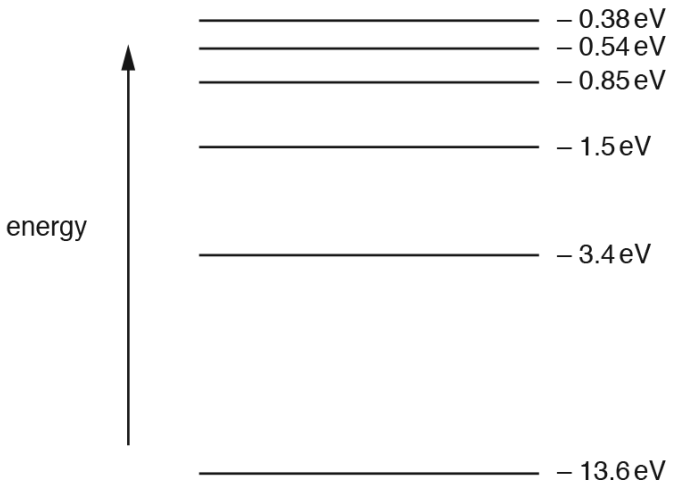


Fig. 11.2 (not to scale)

(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.

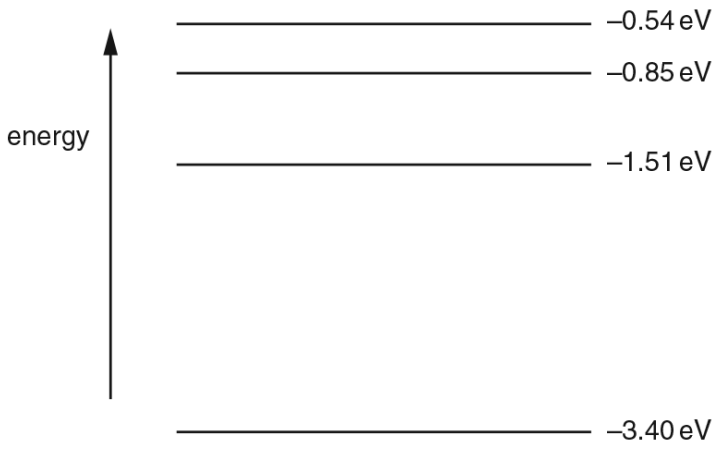


Fig. 12.1

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.

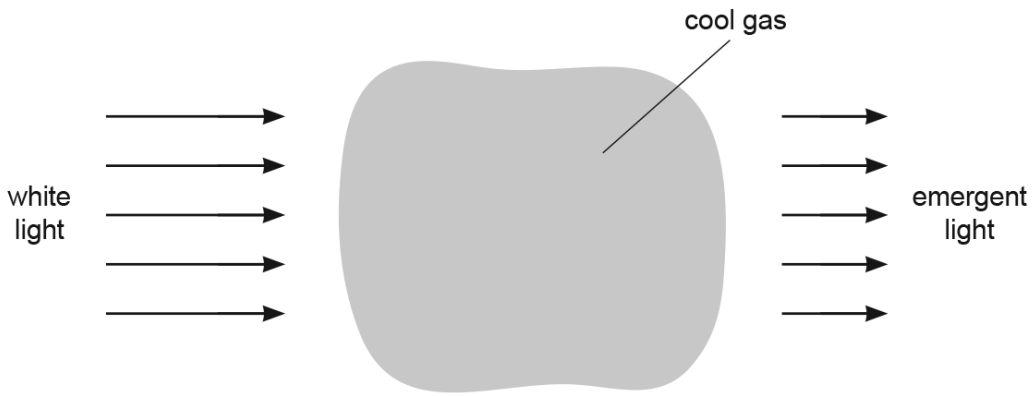


Fig. 10.1

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.

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..... [4]

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

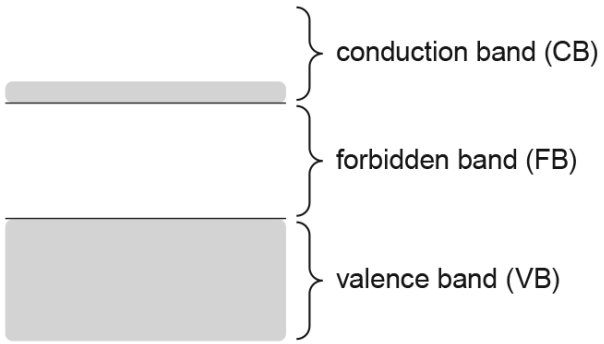


Fig. 10.2

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]

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.

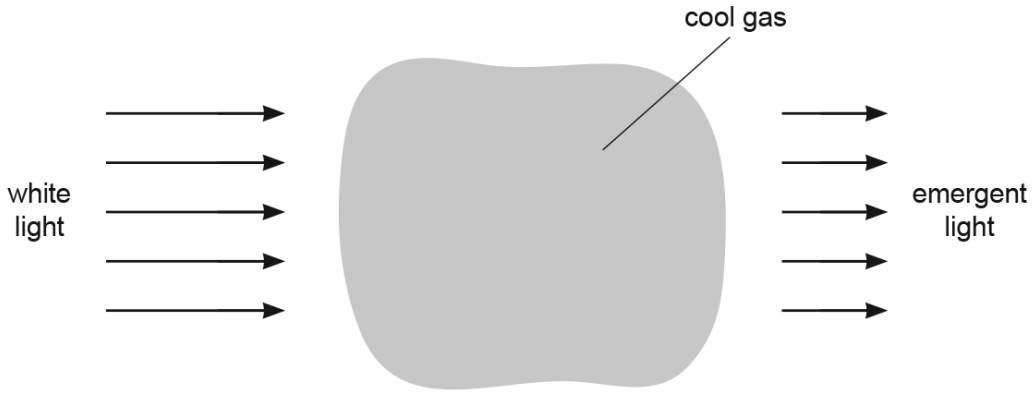


Fig. 10.1

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.

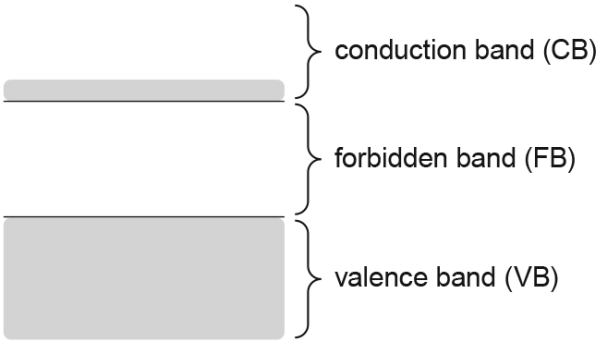


Fig. 10.2

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*.

.....

.....

..... [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.

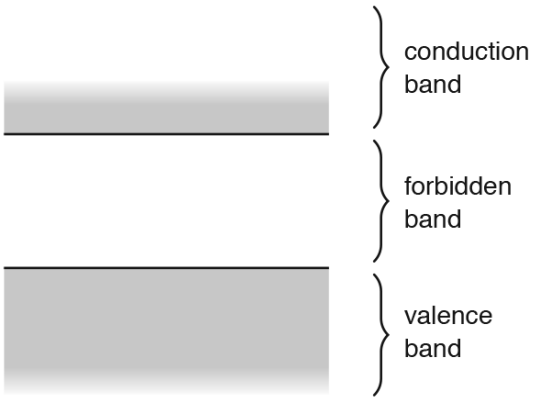


Fig. 10.1

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.

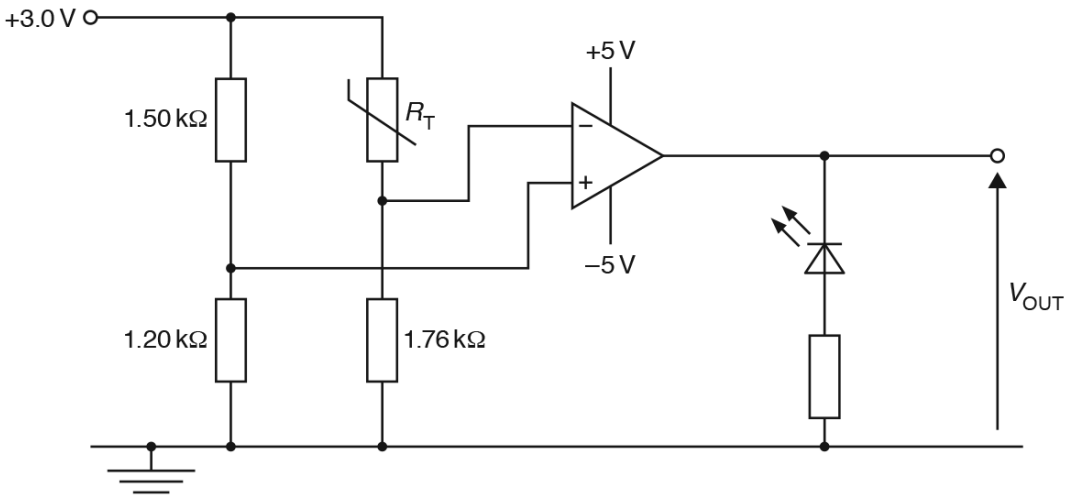


Fig. 10.2

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

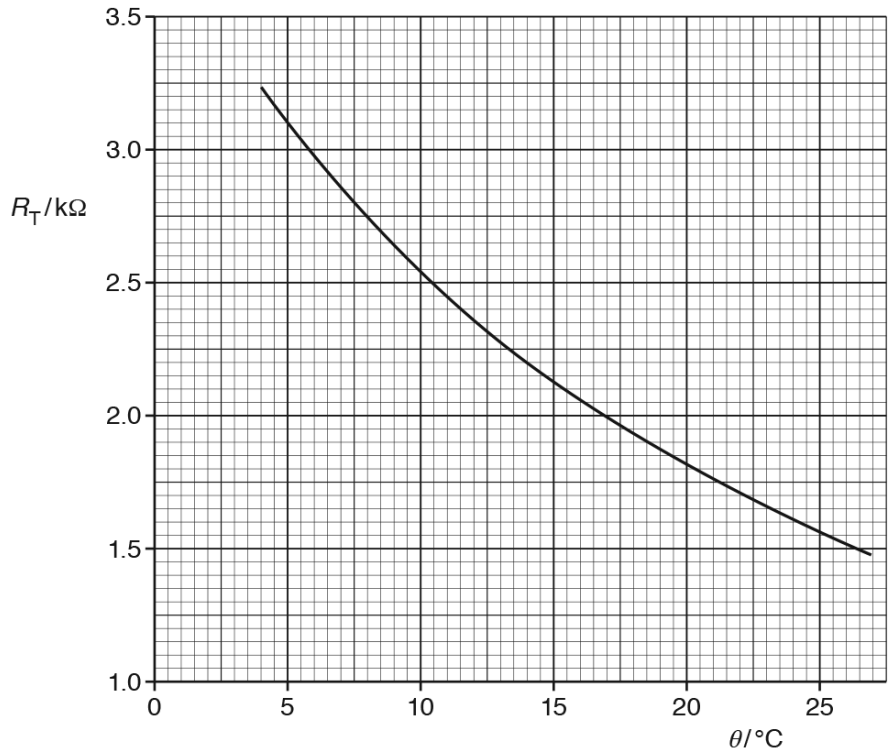


Fig. 10.3

(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]

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370. 9702_m18_qp_42 Q: 11

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

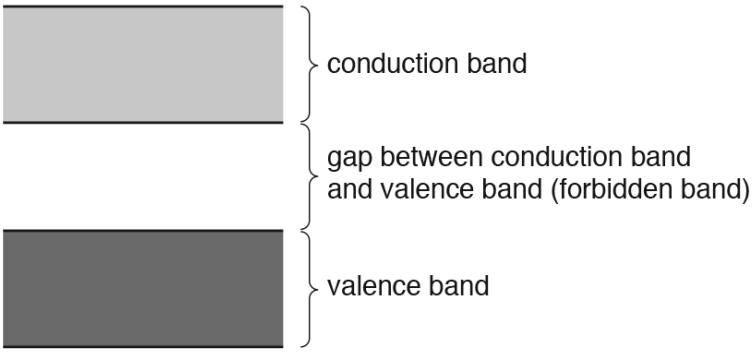


Fig. 11.1

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*.

.....

.....

.....[2]

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

.....

.....[1]

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

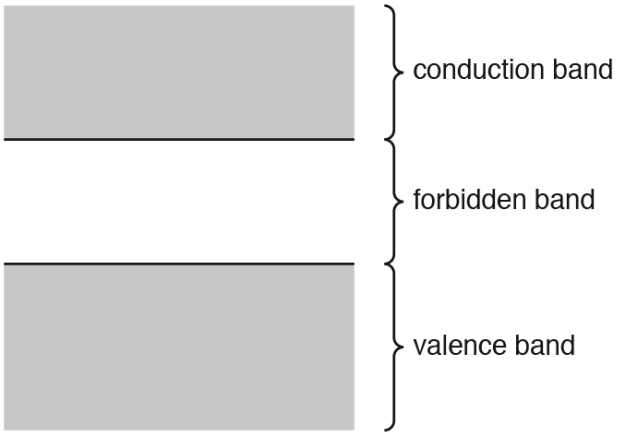


Fig. 11.1

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.

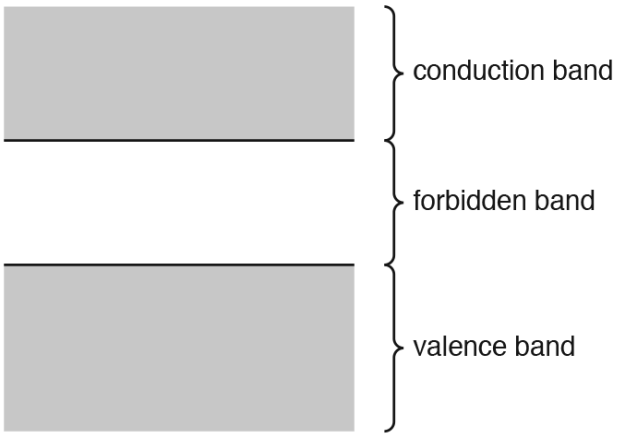


Fig. 11.1

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.

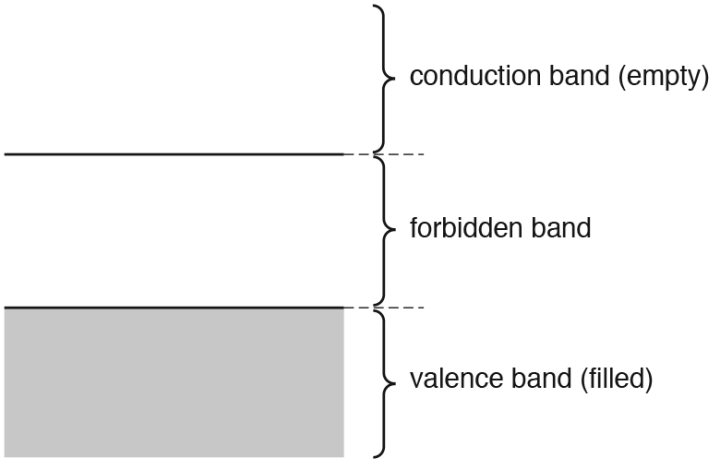


Fig. 10.1

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.

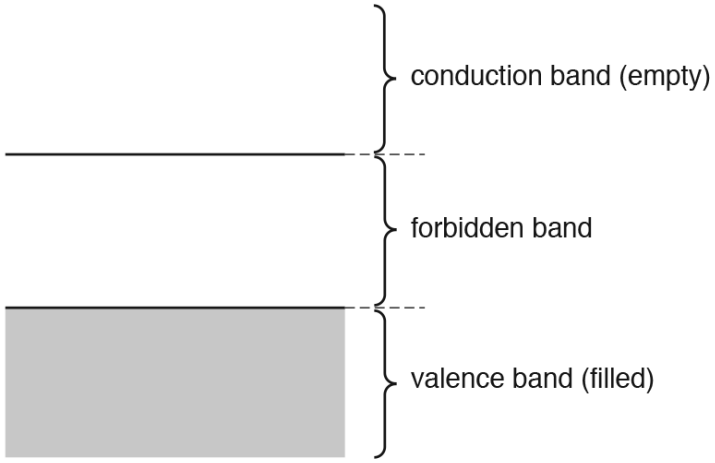


Fig. 10.1

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.

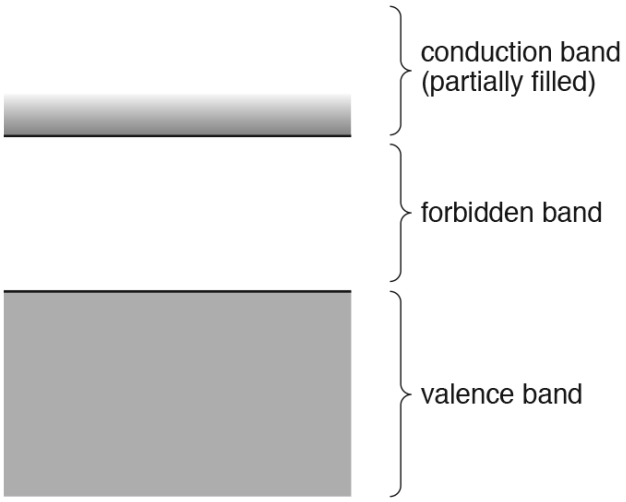


Fig. 11.1

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.

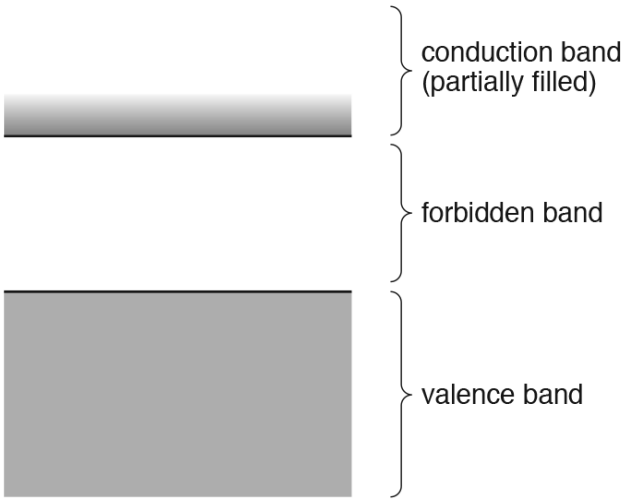


Fig. 11.1

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.

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.....

.....

..... [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).

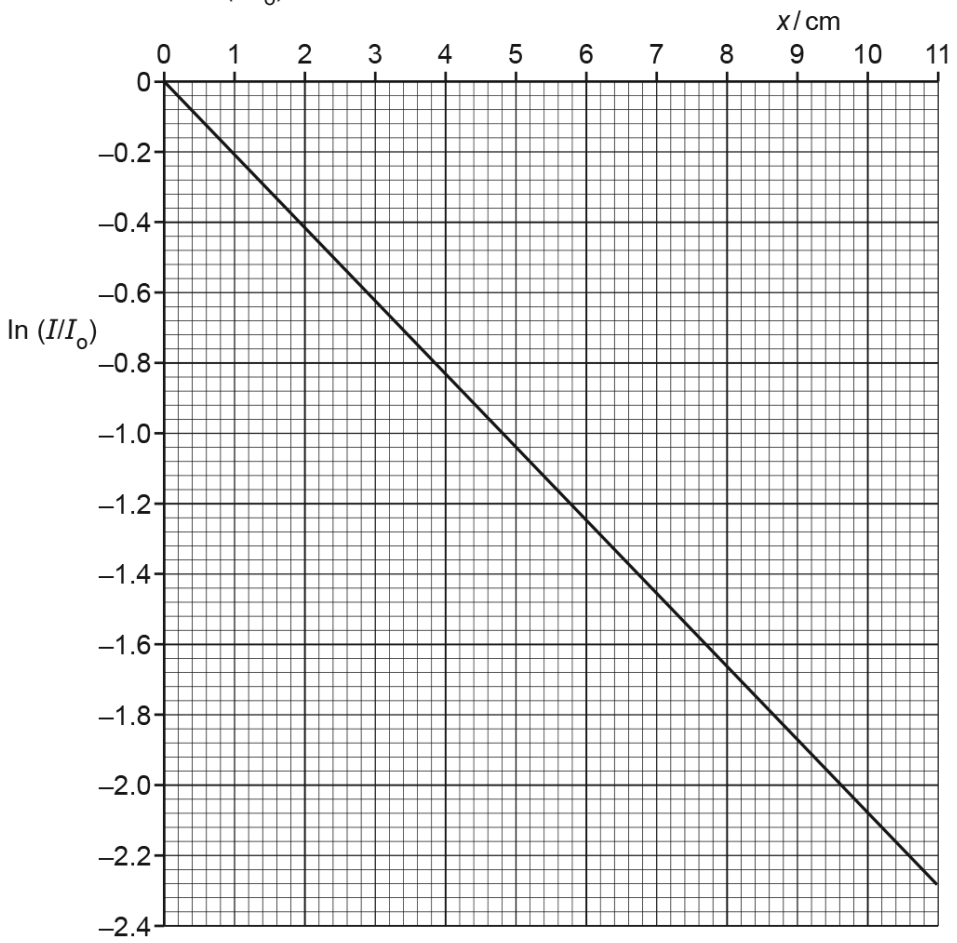


Fig. 11.1

(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.

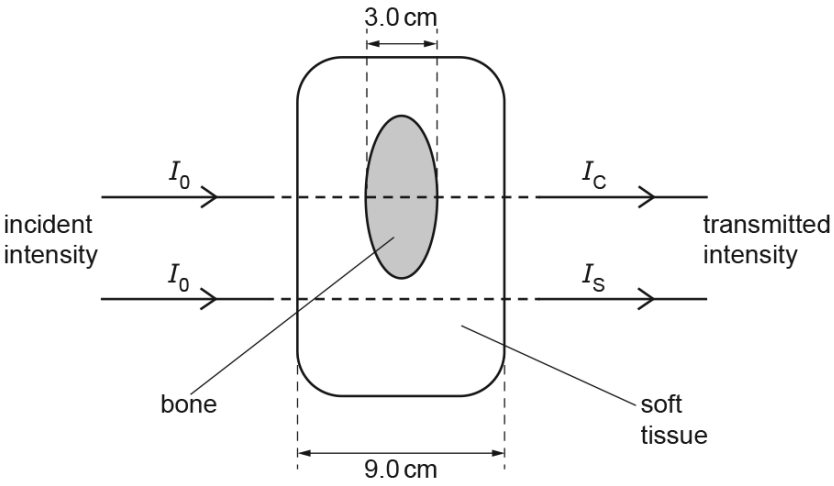


Fig. 11.1

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]

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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.

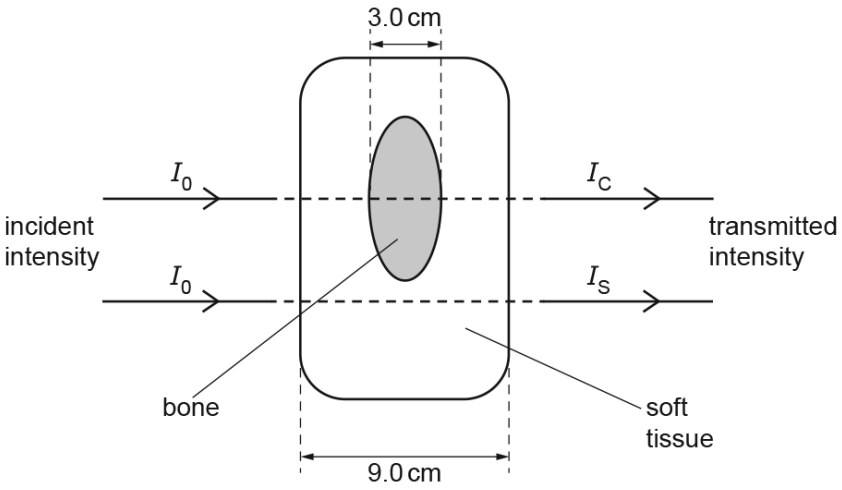


Fig. 11.1

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]

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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.

.....

.....

.....

.....

.....

..... [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.

.....

.....

..... [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]

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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.

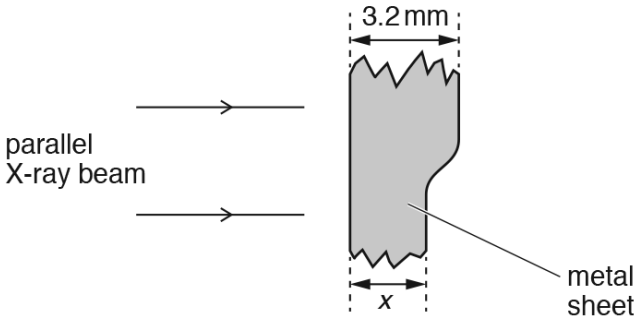


Fig. 12.1 (not to scale)

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.

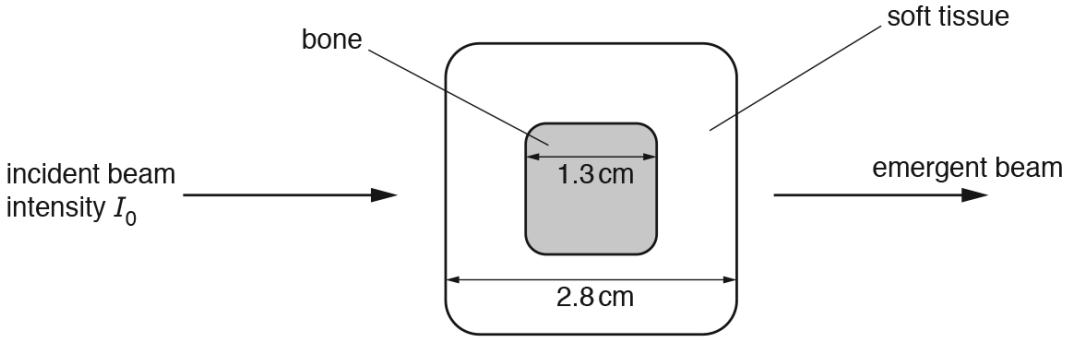


Fig. 12.1

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.

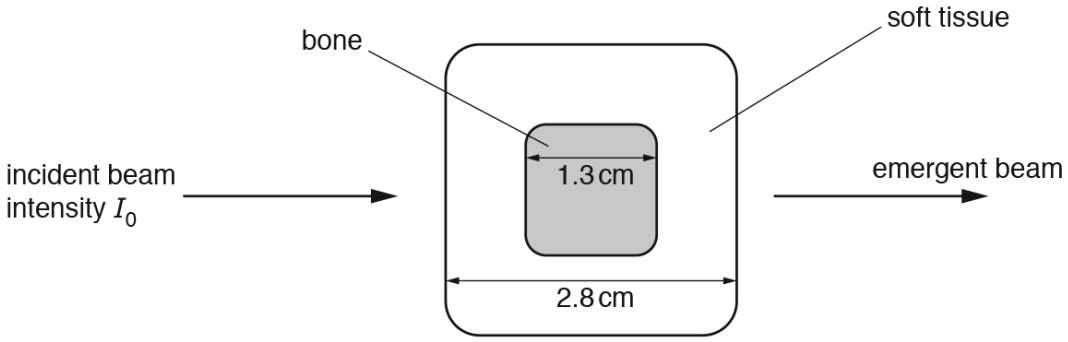


Fig. 12.1

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.

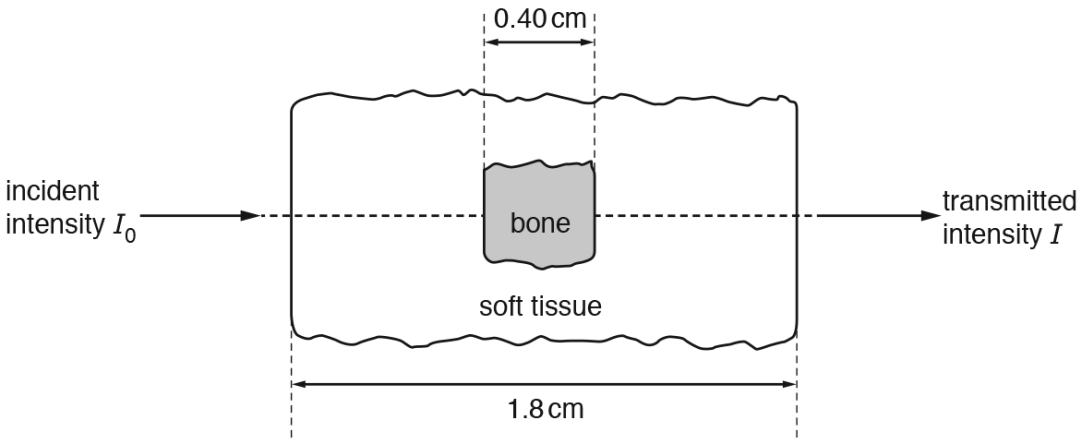


Fig. 10.1

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 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.

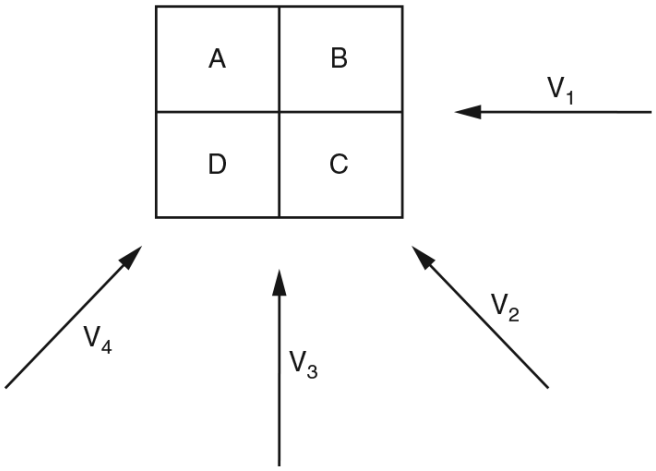


Fig. 9.1

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.

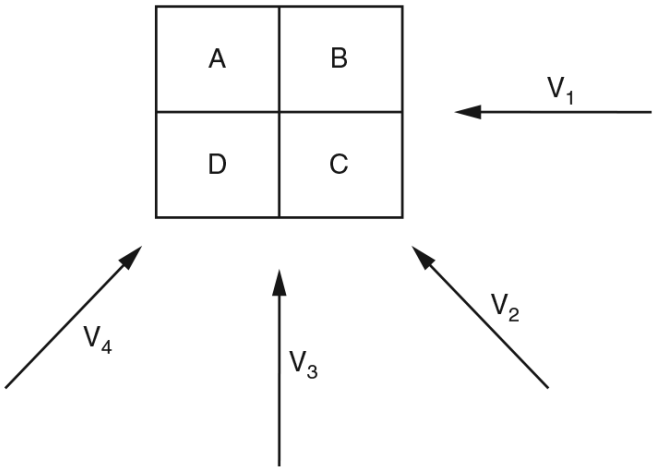


Fig. 9.1

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]

---

396. 9702_w16_qp_42 Q: 13

Outline the principles of computed tomography (CT scanning).

.....

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.....

.....

.....[6]

[Total: 6]

Q1.

7 **(a)** State the de Broglie relation, explaining any symbols you use.

.....

.....

..... [2]

(b) An electron of mass m has kinetic energy E. Show that the de Broglie wavelength λ of this electron is given by

$$\lambda = \frac{h}{\sqrt{2mE}}.$$

[2]

(c) Calculate the potential difference through which an electron, initially at rest, must be accelerated so that its de Broglie wavelength is equal to 0.40 nm (the diameter of an atom).

potential difference = ... V [3]

Q2.

7 A parallel beam of electrons, all travelling at the same speed, is incident normally on a carbon film. The scattering of the electrons by the film is observed on a fluorescent screen, as illustrated in Fig. 7.1.

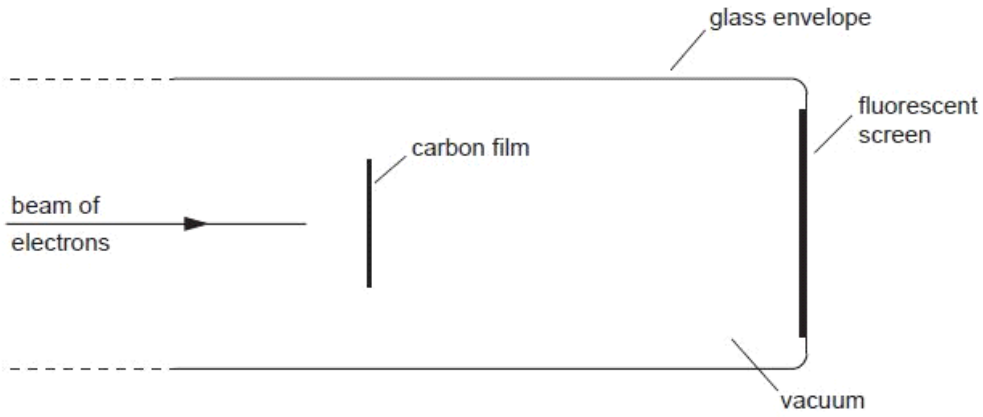


Fig. 7.1

(a) Assuming that the electrons behave as **particles**, predict what would be seen on the screen.

.....

..... [1]

(b) In this experiment, the electrons do **not** behave as particles.

Describe briefly the pattern that is actually observed on the screen. You may draw a sketch if you wish.

.....

..... [1]

(c) The speed of the electrons is gradually increased.

State and explain what change, if any, is observed in the pattern on the screen.

.....

.....

.....

..... [3]

Q3.

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

.....

..... [1]

(ii) Show that the photon energy of light of wavelength 350 nm is 5.68×10^{-19} J. [1]

(iii) State the value of the ratio

$$\frac{\text{energy of photon of light of wavelength 700 nm}}{\text{energy of photon of light of wavelength 350 nm}}.$$

ratio = ... [1]

(b) Two beams of monochromatic light have similar intensities. The light in one beam has wavelength 350 nm and the light in the other beam has wavelength 700 nm.

The two beams are incident separately on three different metal surfaces. The work function of each of these surfaces is shown in Fig. 5.1.

metal	work function / eV
tungsten	4.49
magnesium	3.68
potassium	2.26

Fig. 5.1

(i) Explain what is meant by the *work function* of the surface.

.....

.....

..... [2]

(ii) State which combination, if any, of monochromatic light and metal surface could give rise to photo-electric emission. Give a quantitative explanation of your answer.

Use

.....

.....

.....

.....

.....

..... [3]

Q4.

7 The Millikan oil-drop experiment enabled the charge on the electron to be determined.

For Examiner Use

(a) State a fundamental property of charge that was suggested by this experiment.

.....

..... [1]

(b) Two parallel metal plates P and Q are situated in a vacuum. The plates are horizontal and separated by a distance of 5.4 mm, as illustrated in Fig. 7.1.

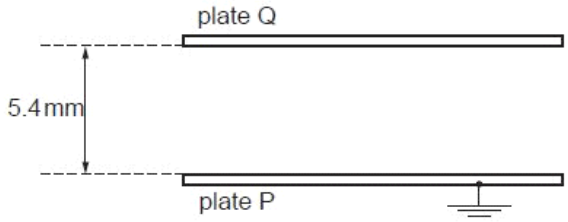


Fig. 7.1

The lower plate P is earthed. The potential difference between the plates can be varied. An oil droplet of mass 7.7×10^{-15} kg is observed to remain stationary between the plates when plate Q is at a potential of +850 V.

(i) Suggest why plates P and Q must be parallel and horizontal.

.....

.....

..... [2]

(ii) Calculate the charge, with its sign, on the oil droplet.

charge = ... C [3]

(c) The procedure in **(b)** was repeated for three further oil droplets. The magnitude of the charge on each of the droplets was found to be 3.2×10^{-19} C, 6.4×10^{-19} C and 3.2×10^{-19} C.
Explain what value these data and your answer in **(b)(ii)** would suggest for the charge on the electron.

.....

.....

.....[1]

Ex

Q5.

8 **(a)** Explain why, for the photoelectric effect, the existence of a threshold frequency and a very short emission time provide evidence for the particulate nature of electromagnetic radiation, as opposed to a wave theory.

.....

.....

.....

.....

.....

..... [4]

Exa

(b) State and explain two relations in which the Planck constant h is the constant of proportionality.

1. .....

.....

.....

.....

2. .....

.....

.....

.....

[6]

Q6.

7 Experiments are conducted to investigate the photoelectric effect.

(a) It is found that, on exposure of a metal surface to light, either electrons are emitted immediately or they are not emitted at all.

Suggest why this observation does not support a wave theory of light.

.....

.....

.....

.....[3]

(b) Data for the wavelength λ of the radiation incident on the metal surface and the maximum kinetic energy E_K of the emitted electrons are shown in Fig. 7.1.

λ/nm	$E_K/10^{-19}$J
650	–
240	4.44

Fig. 7.1

(i) Without any calculation, suggest why no value is given for E_K for radiation of wavelength 650 nm.

.....

.....[1]

(ii) Use data from Fig. 7.1 to determine the work function energy of the surface.

work function energy = ... J [3]

(c) Radiation of wavelength 240 nm gives rise to a maximum photoelectric current I. The intensity of the incident radiation is maintained constant and the wavelength is now reduced.

State and explain the effect of this change on

(i) the maximum kinetic energy of the photoelectrons,

.....

.....

.....[2]

(ii) the maximum photoelectric current I.

.....

.....

.....[2]

Q7.

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

.....

.....

..... [2]

(b) An electron is accelerated in a vacuum from rest through a potential difference of 850 V.

(i) Show that the final momentum of the electron is 1.6×10^{-23} N s.

[2]

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

wavelength = ... m [2]

(c) Describe an experiment to demonstrate the wave nature of electrons.
You may draw a diagram if you wish.

For Examiner's Use

.....

.....

.....

.....

.....

..... [5]

Q8.

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

For Examiner Use

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.....

..... [3]

(b) An emission spectrum is seen as a series of differently coloured lines on a black background.

Suggest how this observation provides evidence for discrete electron energy levels in atoms.

.....

.....

.....

..... [2]

Q9.

6 **(a)** Describe the main principles of the determination of the charge on an oil drop by Millikan's experiment. You may draw a diagram if you wish.

Exa

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....[7]

(b) In an experiment to determine the fundamental charge, values of charge on oil drops were found by a student to be as shown below.

3.2×10^{-19}C; 6.4×10^{-19}C; 16×10^{-19}C; 9.7×10^{-19}C;

12.8×10^{-19}C; 3.1×10^{-19}C; 6.3×10^{-19}C.

State the value, to two significant figures, of the fundamental charge that is suggested by these values of charge on oil drops.

fundamental charge = ... C [1]

Q10.

7 The photoelectric effect may be represented by the equation

photon energy = work function energy + maximum kinetic energy of electron.

(a) State what is meant by *work function energy*.

.....

.....[1]

(b) The variation with frequency f of the maximum kinetic energy E_K of photoelectrons emitted from the surface of sodium metal is shown in Fig. 7.1.

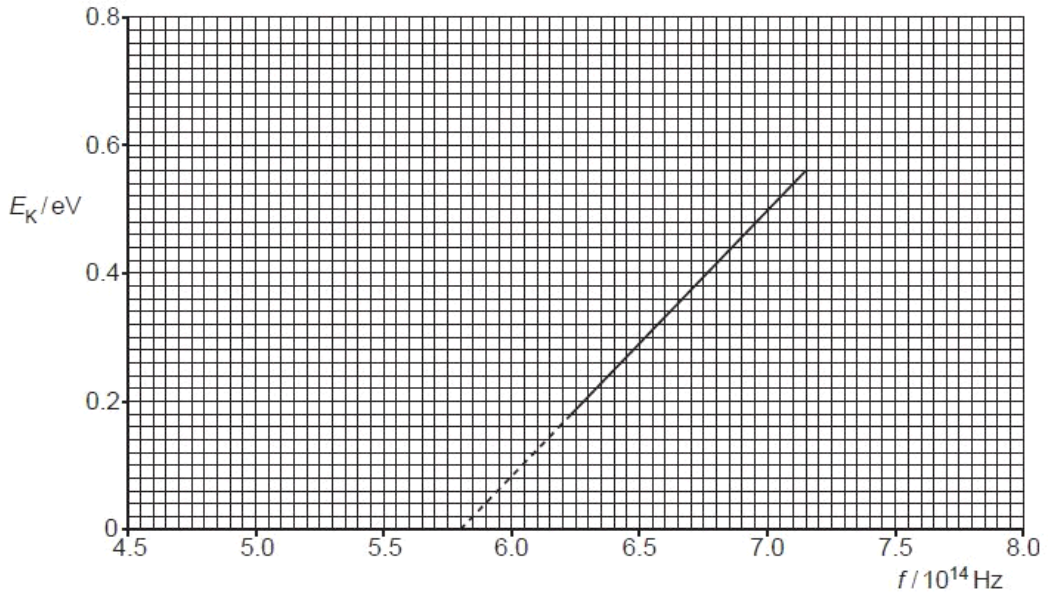


Fig. 7.1

Use the gradient of the graph of Fig. 7.1 to determine a value for the Planck constant h. Show your working.

h = ... J s [2]

(c) The sodium metal in **(b)** has a work function energy of 2.4 eV. The sodium is replaced by calcium which has a work function energy of 2.9 eV.

On Fig. 7.1, draw a line to show the variation with frequency f of the maximum kinetic energy E_K of photoelectrons emitted from the surface of calcium. [3]

Q11.

7 Some data for the work function energy Φ and the threshold frequency f_0 of some metal surfaces are given in Fig. 7.1.

For Examin Use

metal	$\Phi / 10^{-19}$ J	$f_0 / 10^{14}$ Hz
sodium	3.8	5.8
zinc	5.8	8.8
platinum	9.0	

Fig. 7.1

(a) (i) State what is meant by the *threshold frequency*.

.....

.....

.....[2]

(ii) Calculate the threshold frequency for platinum.

threshold frequency = ... Hz [2]

(b) Electromagnetic radiation having a continuous spectrum of wavelengths between 300 nm and 600 nm is incident, in turn, on each of the metals listed in Fig. 7.1.
Determine which metals, if any, will give rise to the emission of electrons.

.....

.....

.....

.....[2]

(c) When light of a particular intensity and frequency is incident on a metal surface, electrons are emitted.
State and explain the effect, if any, on the rate of emission of electrons from this surface for light of the same intensity and higher frequency.

.....

.....

.....

.....[3]

Q12.

7 **(a)** The emission spectrum of atomic hydrogen consists of a number of discrete wavelengths. Explain how this observation leads to an understanding that there are discrete electron energy levels in atoms.

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..... [2]

(b) Some electron energy levels in atomic hydrogen are illustrated in Fig. 7.1.

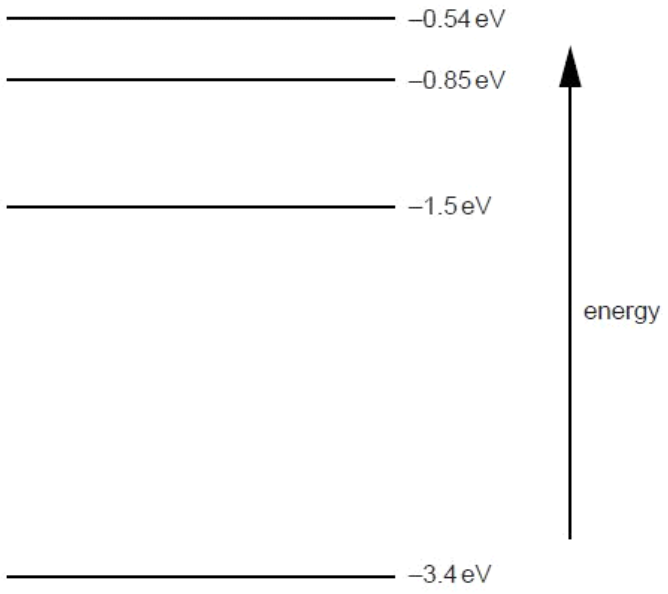


Fig. 7.1

The longest wavelength produced as a result of electron transitions between two of the energy levels shown in Fig. 7.1 is 4.0×10^{-6} m.

For Examiner Use

(i) On Fig. 7.1,

1. draw, and mark with the letter L, the transition giving rise to the wavelength of 4.0×10^{-6} m, [1]

2. draw, and mark with the letter S, the transition giving rise to the shortest wavelength. [1]

(ii) Calculate the wavelength for the transition you have shown in **(i) part 2**.

wavelength = ... m [3]

(c) Photon energies in the visible spectrum vary between approximately 3.66 eV and 1.83 eV.

Determine the energies, in eV, of photons in the visible spectrum that are produced by transitions between the energy levels shown in Fig. 7.1.

photon energies ..... eV [2]

Q13.

Use

2 Fig. 2.1 gives information on three lines observed in the emission spectrum of hydrogen atoms.

wavelength / nm	photon energy / 10^{-19} J
656	3.03
486	.....
1880	1.06

Fig. 2.1

(a) Complete Fig. 2.1 by calculating the photon energy for the wavelength of 486 nm.

[2]

(b) Fig. 2.2 is a partially completed diagram to show energy levels of a hydrogen atom.

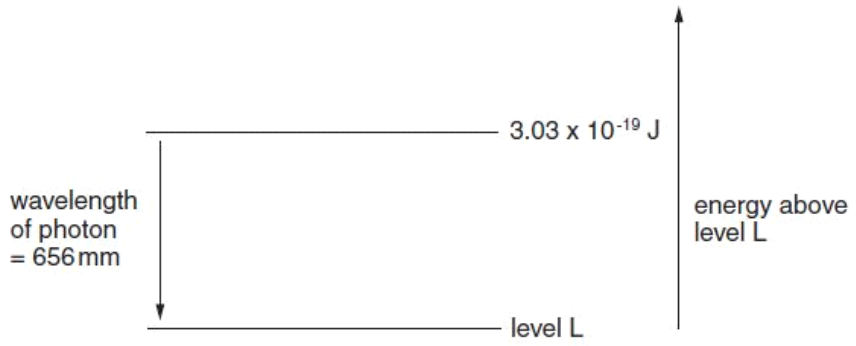


Fig. 2.2

On Fig. 2.2 draw one further labelled energy level, and complete the diagram with arrows to show the energy changes for the other two wavelengths. [3]

Q14.

6 **(a)** Explain what is meant by a *photon* of electromagnetic radiation.

.....

.....

..... [2]

(b) The photoelectric effect provides evidence for the particulate nature of electromagnetic radiation. State three experimental observations that support this conclusion.

1. .....

.....

2. .....

.....

3. .....

..... [3]

(c) Electromagnetic radiation of wavelength λ and intensity I, when incident on a metal surface, causes n electrons to be ejected per unit time. The maximum kinetic energy of the electrons is E_{max}.

State and explain the effect, if any, on n and E_{max} when

(i) the intensity is reduced to $\frac{1}{2}I$ but the wavelength λ is unchanged,

.....

.....

.....

(ii) the wavelength λ is reduced but the intensity I is not changed.

.....

.....

.....

[4]

Q15.

7 The photoelectric effect may be summarised in terms of the word equation

photon energy = work function energy + maximum kinetic energy of emitted electrons.

(a) Explain

(i) what is meant by a *photon*,

.....

.....

..... [2]

(ii) why most electrons are emitted with kinetic energy less than the maximum.

.....

.....

..... [2]

(b) Light of constant intensity is incident on a metal surface, causing electrons to be emitted.

State and explain why the rate of emission of electrons changes as the frequency of the incident light is increased.

.....

.....

..... [2]

Q16.

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

For Examiner Use

1. .....

.....

2. .....

.....

3. .....

.....

[3]

(b) **(i)** Briefly describe the concept of a photon.

.....

.....

..... [2]

(ii) Explain how lines in the emission spectrum of gases at low pressure provide evidence for discrete electron energy levels in atoms.

.....

.....

..... [2]

(c) Three electron energy levels in atomic hydrogen are represented in Fig. 7.1.

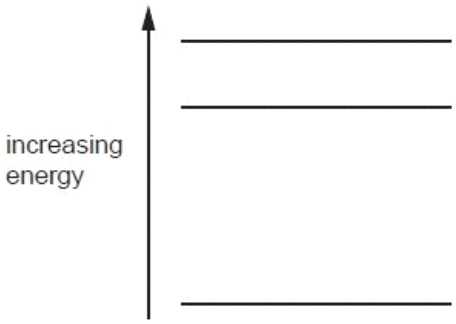


Fig. 7.1

The wavelengths of the spectral lines produced by electron transitions between these three energy levels are 486 nm, 656 nm and 1880 nm.

(i) On Fig. 7.1, draw arrows to show the electron transitions between the energy levels that would give rise to these wavelengths.
Label each arrow with the wavelength of the emitted photon. [3]

(ii) Calculate the maximum change in energy of an electron when making transitions between these levels.

energy = ...J [3]

Q17.

7 **(a)** Explain how a line emission spectrum leads to an understanding of the existence of discrete electron energy levels in atoms.

For Examiner Use

.....

.....

.....

..... [3]

(b) Some of the lines of the emission spectrum of atomic hydrogen are shown in Fig. 7.1.

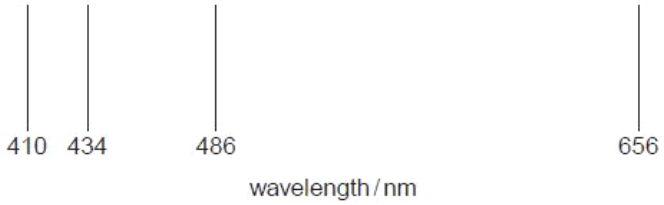


Fig. 7.1

The photon energies associated with some of these lines are shown in Fig. 7.2.

wavelength / nm	photon energy / 10^{-19} J
410	4.85
434	4.58
486	.....
656	3.03

Fig. 7.2

(i) Complete Fig. 7.2 by calculating the photon energy for a wavelength of 486 nm.

[2]

(ii) Energy levels of a single electron in a hydrogen atom are shown in Fig. 7.3.

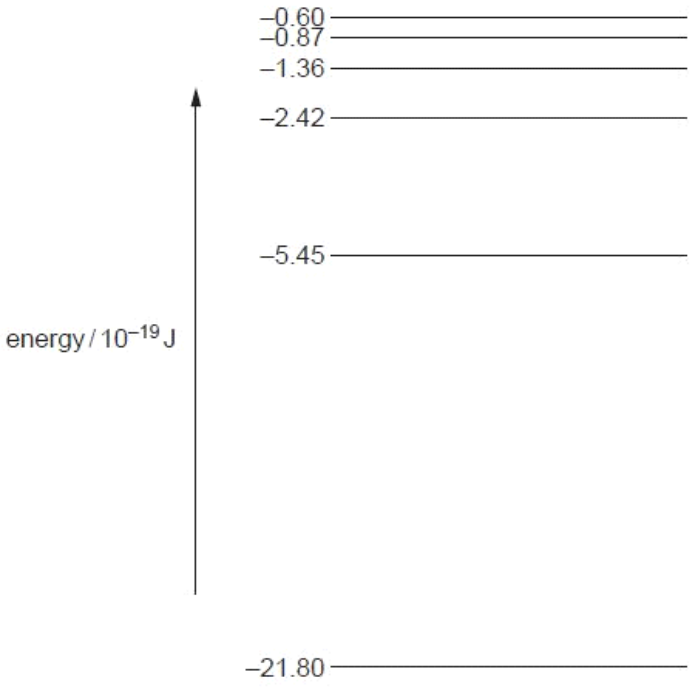


Fig. 7.3 (not to scale)

Use data from **(i)** to show, on Fig. 7.3, the transitions associated with each of the four spectral lines shown in Fig. 7.1. Show each transition with an arrow. [2]

Q18.

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

For Examiner Use

(i) the wave nature of a particle,

.....[1]

(ii) the particulate nature of electromagnetic radiation.

.....[1]

(b) Four electron energy levels in an atom are shown in Fig. 7.1.

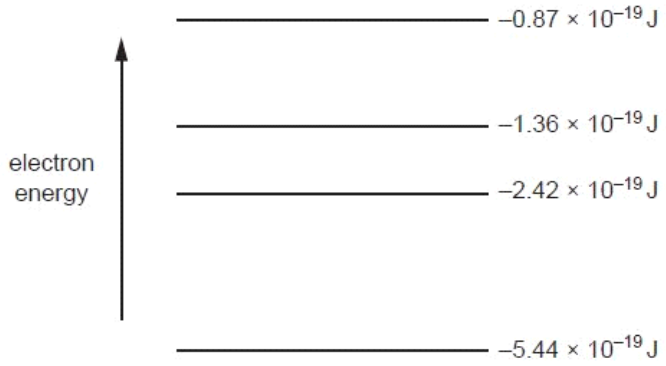


Fig. 7.1 (not to scale)

An emission spectrum is associated with the electron transitions between these energy levels.
For this spectrum,

(i) state the number of lines,

.....[1]

(ii) calculate the minimum wavelength.

wavelength = ... m [2]

Q19.

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

.....

.....

..... [2]

(b) The surface of a zinc plate has a work function of 5.8×10^{-19} J.
In a particular laboratory experiment, ultraviolet light of wavelength 120 nm is incident on the zinc plate. A photoelectric current I is detected.
In order to view the apparatus more clearly, a second lamp emitting light of wavelength 450 nm is switched on. No change is made to the ultraviolet lamp.

Using appropriate calculations, state and explain the effect on the photoelectric current of switching on this second lamp.

.....

..... [4]

Q20.

7 **(a)** Explain how the line spectrum of hydrogen provides evidence for the existence of discrete electron energy levels in atoms.

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.....[3]

(b) Some electron energy levels in atomic hydrogen are illustrated in Fig. 7.1.

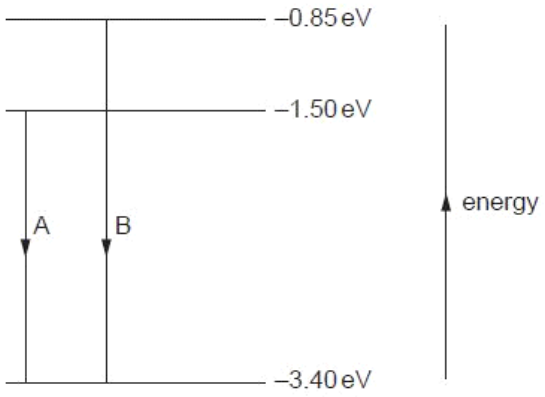


Fig. 7.1

Two possible electron transitions A and B giving rise to an emission spectrum are shown.
These electron transitions cause light of wavelengths 654 nm and 488 nm to be emitted.

(i) On Fig. 7.1, draw an arrow to show a third possible transition. [1]

(ii) Calculate the wavelength of the emitted light for the transition in **(i)**.

wavelength = ... m [3]

(c) The light in a beam has a continuous spectrum of wavelengths from 400 nm to 700 nm. The light is incident on some cool hydrogen gas, as illustrated in Fig. 7.2.

For Examiner's Use

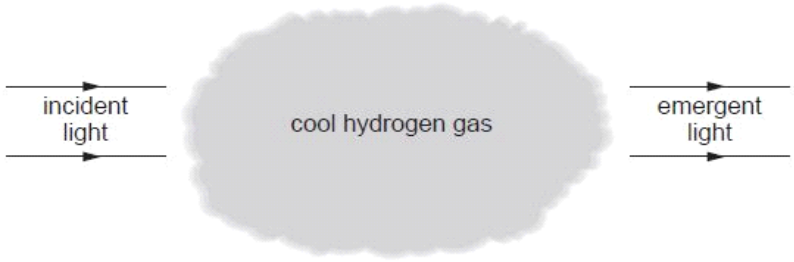


Fig. 7.2

Using the values of wavelength in **(b)**, state and explain the appearance of the spectrum of the emergent light.

.....

.....

.....

.....

.....

.....[4]

Q21.

7 An explanation of the photoelectric effect includes the terms photon energy and work function energy.

For Examine Use

(a) Explain what is meant by

(i) a *photon*,

.....

.....

..... [2]

(ii) *work function energy*.

.....

..... [1]

(b) In an experiment to investigate the photoelectric effect, a student measures the wavelength λ of the light incident on a metal surface and the maximum kinetic energy E_{max} of the emitted electrons. The variation with E_{max} of $\frac{1}{\lambda}$ is shown in Fig. 7.1.

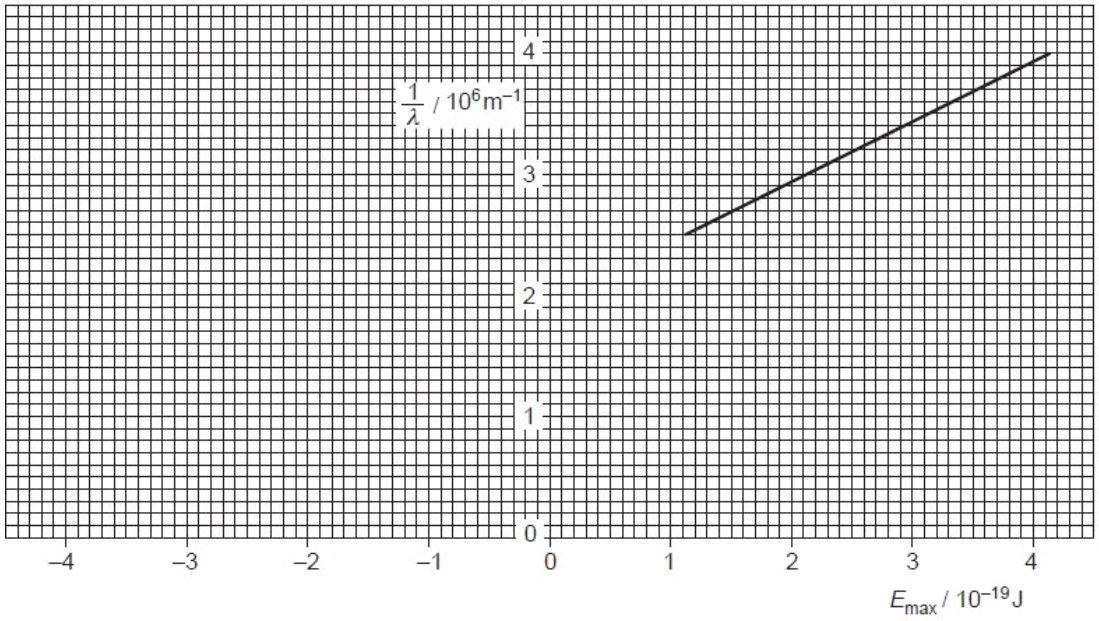


Fig. 7.1

(i) The work function energy of the metal surface is Φ.
State an equation, in terms of λ, Φ and E_{max}, to represent conservation of energy for the photoelectric effect. Explain any other symbols you use.

.....

.....

..... [2]

(ii) Use your answer in **(i)** and Fig. 7.1 to determine

For Examiner's Use

1. the work function energy Φ of the metal surface,

Φ = ... J [2]

2. a value for the Planck constant.

Planck constant = ... J s [3]

Q22.

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

For Examiner's Use

.....

.....

.....[2]

(b) It has been observed that, where photoelectric emission of electrons takes place, there is negligible time delay between illumination of the surface and emission of an electron.

State three other pieces of evidence provided by the photoelectric effect for the particulate nature of electromagnetic radiation.

1. .....

.....

2. .....

.....

3. .....

.....

[3]

(c) The work function of a metal surface is 3.5 eV. Light of wavelength 450 nm is incident on the surface.
Determine whether electrons will be emitted, by the photoelectric effect, from the surface.

[3]

Q23.

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

For Examine Use

.....

.....

.....[2]

(b) An electron is accelerated from rest in a vacuum through a potential difference of 4.7 kV.

(i) Calculate the de Broglie wavelength of the accelerated electron.

wavelength = ... m [5]

(ii) By reference to your answer in **(i)**, suggest why such electrons may assist with an understanding of crystal structure.

.....

.....

.....

.....[2]

Q24.

7 Electrons, travelling at speed v in a vacuum, are incident on a very thin carbon film, as illustrated in Fig. 7.1.

For Examiner's Use

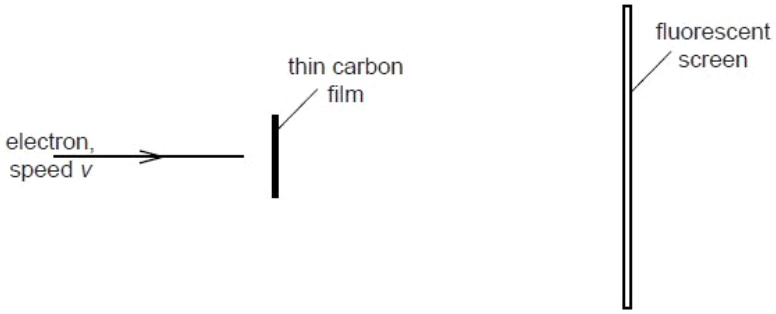


Fig. 7.1

The emergent electrons are incident on a fluorescent screen.
A series of concentric rings is observed on the screen.

(a) Suggest why the observed rings provide evidence for the wave nature of particles.

.....

.....

.....

.....[2]

(b) The initial speed of the electrons is increased. State and explain the effect, if any, on the radii of the rings observed on the screen.

.....

.....

.....

.....[3]

(c) A proton and an electron are each accelerated from rest through the same potential difference.
Determine the ratio

$$\frac{\text{de Broglie wavelength of the proton}}{\text{de Broglie wavelength of the electron}}.$$

ratio = ...[4]

For Examiner Use

Q25.

7 **(a)** By reference to the photoelectric effect, explain

(i) what is meant by *work function energy*,

.....

.....

.....[2]

(ii) why, even when the incident light is monochromatic, the emitted electrons have a range of kinetic energy up to a maximum value.

.....

.....

.....[2]

For Examiner's Use

(b) Electromagnetic radiation of frequency f is incident on a metal surface. The variation with frequency f of the maximum kinetic energy E_{MAX} of electrons emitted from the surface is shown in Fig. 7.1.

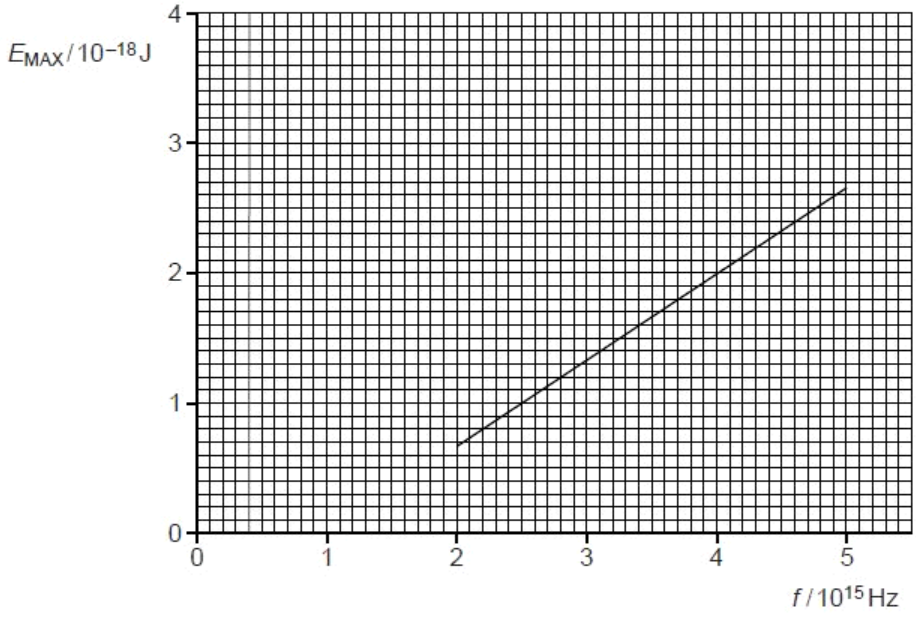


Fig. 7.1

(i) Use Fig. 7.1 to determine the work function energy of the metal surface.

For Examiner's Use

work function energy = ... J [3]

(ii) A second metal has a greater work function energy than that in **(i)**.
On Fig. 7.1, draw a line to show the variation with f of E_{MAX} for this metal. [2]

(iii) Explain why the graphs in **(i)** and **(ii)** do not depend on the intensity of the incident radiation.

.....

.....

.....[2]

Q26.

8 (a) State what is meant by *quantisation* of charge.

.....

..... [1]

(b) A student carries out an experiment to determine the elementary charge.
A charged oil drop is positioned between two horizontal metal plates, as shown in Fig. 8.1.

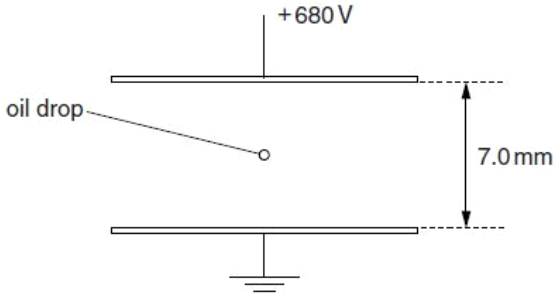


Fig. 8.1

The plates are separated by a distance of 7.0 mm. The lower plate is earthed.
The potential of the upper plate is gradually increased until the drop is held stationary. The potential for the drop to be stationary is 680 V.
The weight of the oil drop, allowing for the upthrust of the air, is 4.8×10^{-14} N.
Calculate the value for the charge on the oil drop.

charge = ... C [2]

(c) The student repeats the experiment and determines the following values for the charge on oil drops.

3.3×10^{-19}C $\quad$ 4.9×10^{-19}C $\quad$ 9.7×10^{-19}C $\quad$ 3.4×10^{-19}C

Use these values to suggest a value for the elementary charge. Explain your working.

elementary charge = ... C [2]

Q27.

9 For a particular metal surface, it is observed that there is a minimum frequency of light below which photoelectric emission does not occur. This observation provides evidence for a particulate nature of electromagnetic radiation.

(a) State three further observations from photoelectric emission that provide evidence for a particulate nature of electromagnetic radiation.

1. .....

.....

2. .....

.....

3. .....

.....

[3]

(b) Some data for the variation with frequency f of the maximum kinetic energy E_{MAX} of electrons emitted from a metal surface are shown in Fig. 9.1.

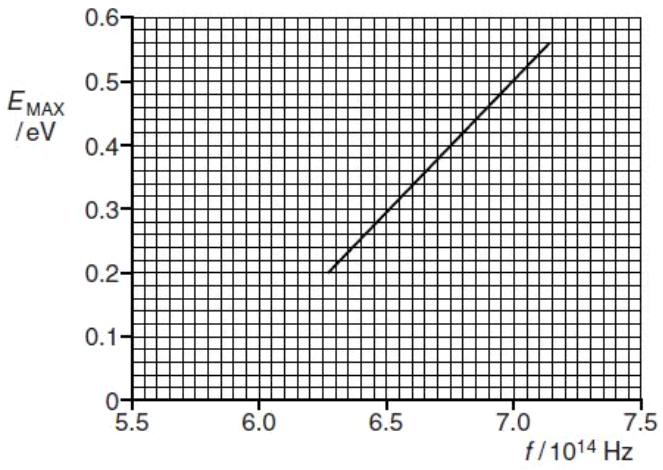


Fig. 9.1

(i) Explain why emitted electrons may have kinetic energy less than the maximum at any particular frequency.

.....

.....

..... [2]

(ii) Use Fig. 9.1 to determine

1. the threshold frequency,

threshold frequency = ... Hz [1]

2. the work function energy, in eV, of the metal surface.

work function energy = ... eV [3]

Q28.

8 Light of wavelength 590 nm is incident normally on a surface, as illustrated in Fig. 8.1.

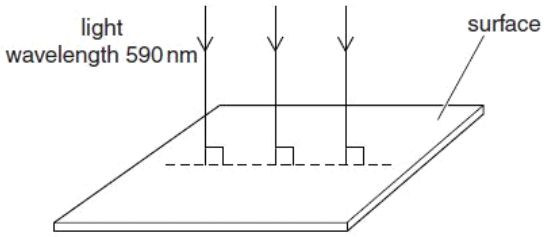


Fig. 8.1

The power of the light is 3.2 mW. The light is completely absorbed by the surface.

(a) Calculate the number of photons incident on the surface in 1.0 s.

number = ... [3]

(b) Use your answer in **(a)** to determine

(i) the total momentum of the photons arriving at the surface in 1.0 s,

momentum = ... $kg\,m\,s^{-1}$ [3]

(ii) the force exerted on the surface by the light.

force = ... N [1]

Q29.

8 White light is incident on a cloud of cool hydrogen gas, as illustrated in Fig. 8.1.

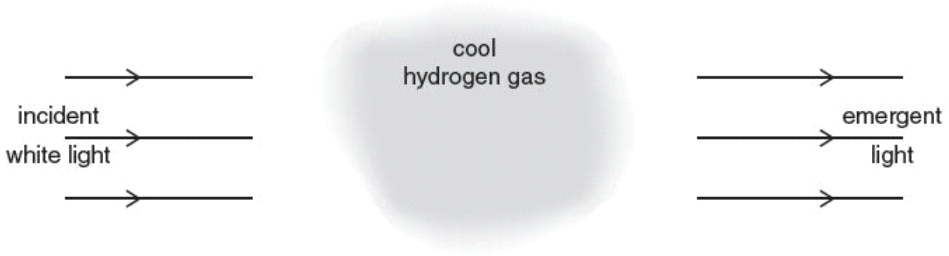


Fig. 8.1

The spectrum of the light emerging from the gas cloud is found to contain a number of dark lines.

(a) Explain why these dark lines occur.

.....

.....

.....

.....

..... [3]

(b) Some electron energy levels in a hydrogen atom are illustrated in Fig. 8.2.

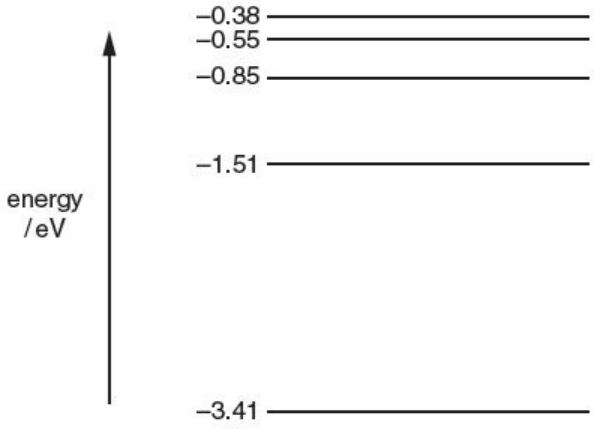


Fig. 8.2

One dark line is observed at a wavelength of 435 nm.

(i) Calculate the energy, in eV, of a photon of light of wavelength 435 nm.

energy = ... eV [4]

(ii) On Fig. 8.2, draw an arrow to indicate the energy change that gives rise to this dark line. [1]

Q30.

7 **(a)** State what is meant by *quantisation* of charge.

.....

..... [1]

(b) Charged parallel plates, as shown in Fig. 7.1, produce a uniform electric field between the plates.

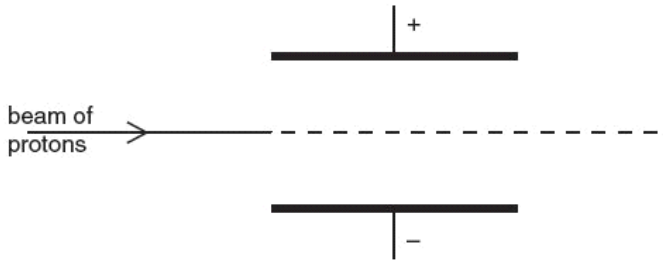


Fig. 7.1

The electric field outside the region between the plates is zero.
A uniform magnetic field is applied in the region between the plates so that a beam of protons passes undeviated between the plates.

(i) State and explain the direction of the magnetic field between the plates.

.....

.....

..... [2]

(ii) The magnetic flux density between the plates is now increased.

On Fig. 7.1, sketch the path of the protons between the plates. [2]

Q31.

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

.....

.....

..... [2]

(b) A beam of light is incident normally on a metal surface, as illustrated in Fig. 8.1.

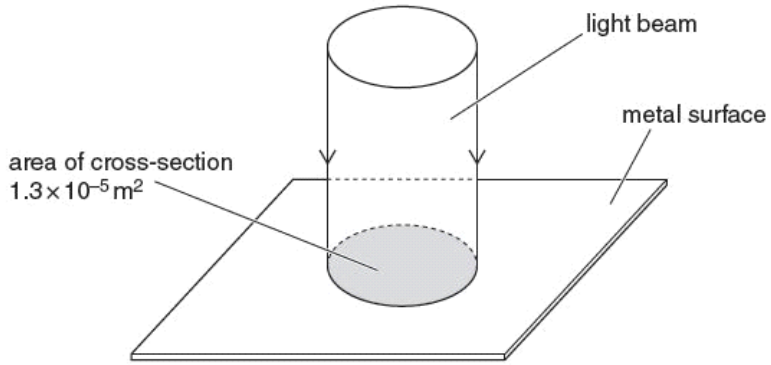


Fig. 8.1

The beam of light has cross-sectional area $1.3 \times 10^{-5}\,m^2$ and power $2.7 \times 10^{-3}\,W$.
The light has wavelength 570 nm.

The light energy is absorbed by the metal and no light is reflected.

(i) Show that a photon of this light has an energy of 3.5×10^{-19} J.

[1]

(ii) Calculate, for a time of 1.0 s,

1. the number of photons incident on the surface,

number = ... [2]

2. the change in momentum of the photons.

change in momentum = ... kg m s^{-1} [3]

(c) Use your answer in **(b)(ii)** to calculate the pressure that the light exerts on the metal surface.

pressure = ... Pa [2]

Q32.

1 **(a)** State the significance of the Millikan experiment.

.....

..... [1]

(b) In the Millikan experiment, oil droplets were found to have the following charges.

1.56×10^{-19} C
4.88×10^{-19} C
1.64×10^{-19} C
3.14×10^{-19} C
4.76×10^{-19} C

Use these data to determine a value for the elementary charge. Explain your working.

.....

.....

elementary charge = ... C [2]

1. Nov/2020/Paper_41/No.11

A photon of wavelength 540 nm collides with an isolated stationary electron, as illustrated in Fig. 11.1.

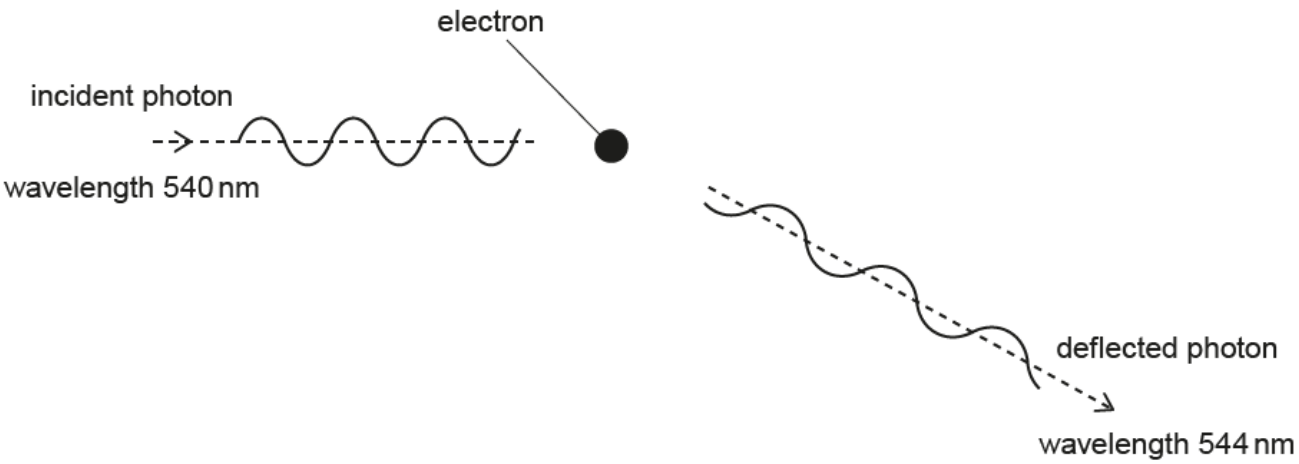


Fig. 11.1

The photon is deflected elastically by the electron.
The wavelength of the deflected photon is 544 nm.

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

.....

.....

..... [2]

(ii) On Fig. 11.1, draw an arrow to indicate the approximate direction of motion of the deflected electron. [1]

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(b) Calculate:

(i) the momentum of the deflected photon

momentum = ... Ns [2]

(ii) the energy transferred to the deflected electron.

energy = ... J [2]

(c) Another photon of wavelength 540 nm collides with an isolated stationary electron.

Explain why it is not possible for the deflected photon to have a wavelength less than 540 nm.

.....

.....

..... [2]

[Total: 9]

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2. Nov/2020/Paper_42/No.11

(a) Electromagnetic radiation is incident on a metal surface.

It is observed that there is a minimum frequency of electromagnetic radiation below which emission of electrons does not occur.

This observation provides evidence for a particulate nature of electromagnetic radiation.

State **two** other observations associated with photoelectric emission that provide evidence for a particulate nature of electromagnetic radiation.

1. .....

.....

2. .....

.....

[2]

(b) The maximum kinetic energy E_{MAX} of electrons emitted from a metal surface is determined for different wavelengths λ of the electromagnetic radiation incident on the surface.

The variation with $\frac{1}{\lambda}$ of E_{MAX} is shown in Fig. 11.1.

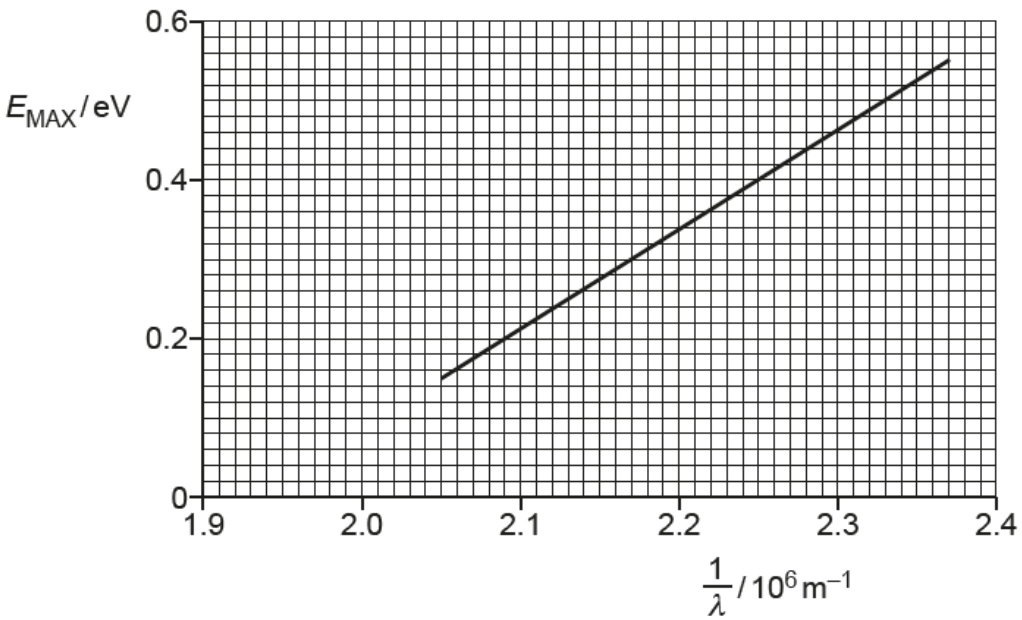


Fig. 11.1

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(i) Use Fig. 11.1 to determine the threshold frequency f_0.

f_0 = ... Hz [2]

(ii) Use the gradient of the line on Fig. 11.1 to determine a value for the Planck constant h. Explain your working.

h = ...Js [4]

(c) The electromagnetic radiation is now incident on a metal with a larger work function energy than the metal in **(b)**.

On Fig. 11.1, sketch the variation with $\frac{1}{\lambda}$ of E_{MAX}. [2]

[Total: 10]

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3. June/2020/Paper_41/No.10

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

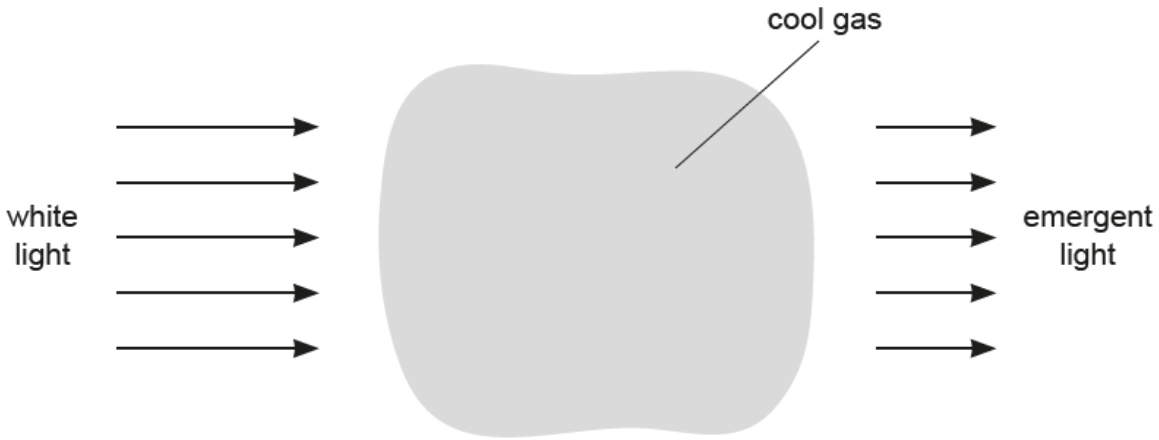


Fig. 10.1

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]

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

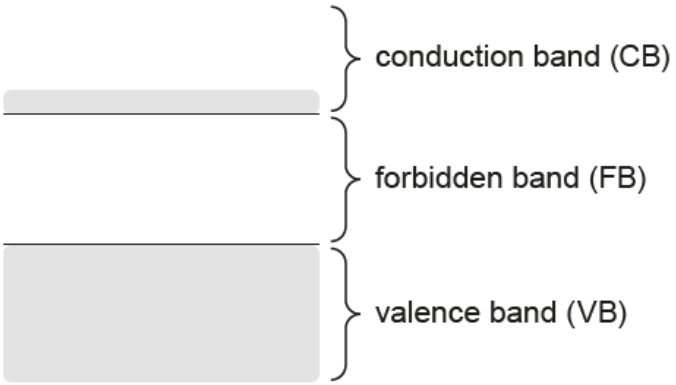


Fig. 10.2

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

.....

.....

.....

.....

.....

.....

..... [5]

[Total: 9]

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4. June/2020/Paper_41/No.11

An electron, at rest, has mass m_e and charge $-q$.

A positron is a particle that, at rest, has mass m_e and charge $+q$.

A positron interacts with an electron. The electron and the positron may be considered to be at rest.
The outcome of this interaction is that the electron and the positron become two gamma-ray (γ-ray) photons, each having the same energy.

(a) Calculate, for one of the γ-ray photons:

(i) the photon energy, in J

energy = ... J [2]

(ii) its momentum.

momentum = ... Ns [2]

(b) State and explain the direction, relative to each other, in which the γ-ray photons are emitted.

.....

.....

.....

..... [2]

[Total: 6]

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5. June/2020/Paper_42/No.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.

.....

.....

.....

.....

.....

.....

..... [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]

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6. March/2020/Paper_42/No.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.

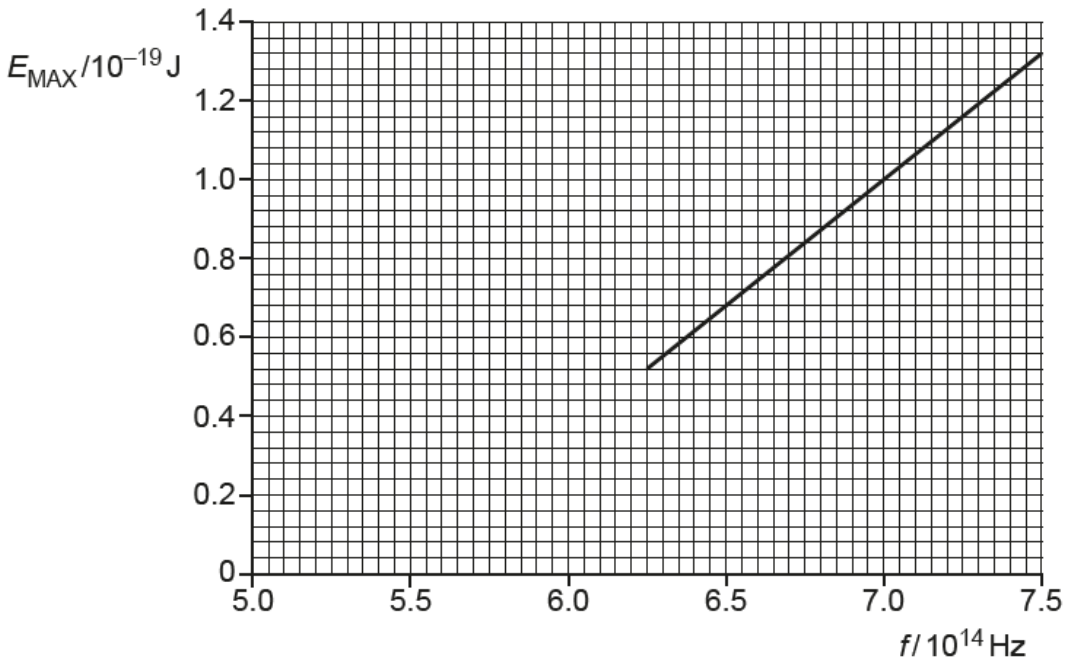


Fig. 10.1

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

work function energy = ... J [2]

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(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]

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1. Nov/2021/Paper_41/No.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 $4.1 \times 10^7\,\text{m s}^{-1}$.

[2]

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

wavelength = ... m [2]

[Total: 9]

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2. Nov/2021/Paper_42/No.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]

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3. June/2021/Paper_41/No.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]

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4. June/2021/Paper_42/No.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]

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(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]

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5. March/2021/Paper_42/No.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]

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(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).

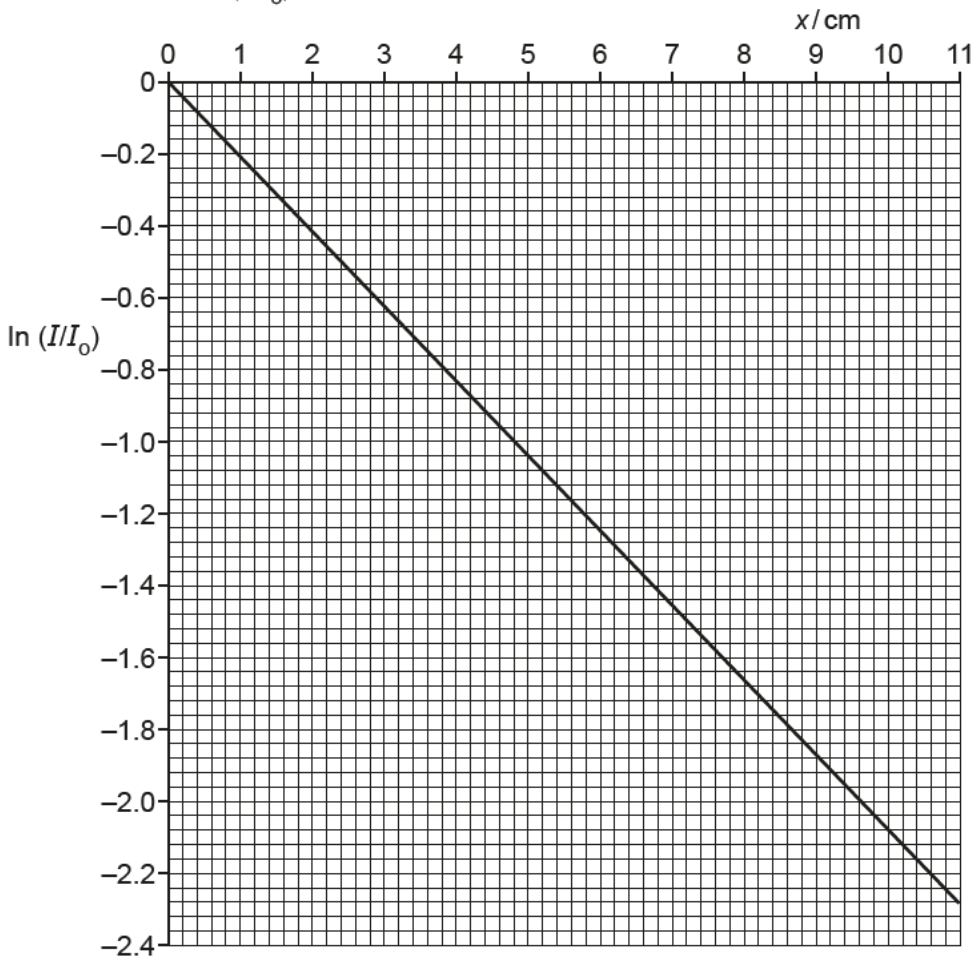


Fig. 11.1

(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]

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1. Nov/2023/Paper_9702/41/No.8

(a) **(i)** Show that the momentum p of a photon of electromagnetic radiation with wavelength λ is given by

$$p = \frac{h}{\lambda}$$

where h is the Planck constant.

[2]

(ii) Use the expression in **(a)(i)** to show that a photon in free space that has a momentum of 9.5×10^{-28} N s is a photon of red light.

[1]

(b) A beam of red light of intensity 160 W m^{-2} is incident normally on a plane mirror, as shown in Fig. 8.1. The momentum of each photon in the beam is 9.5×10^{-28} N s.

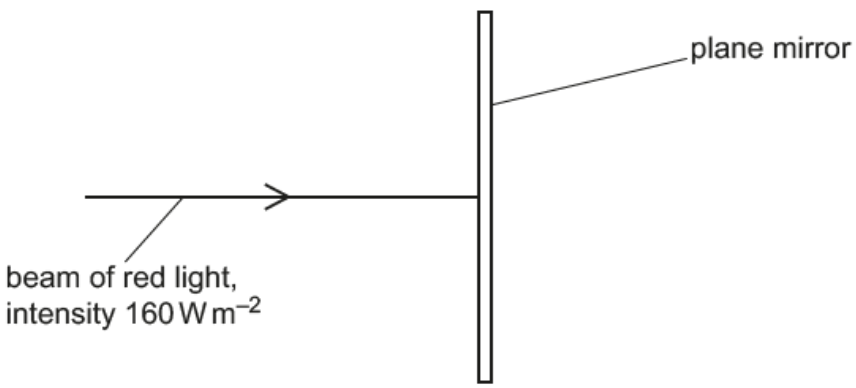


Fig. 8.1

All of the light is reflected by the mirror in the opposite direction to its original path.
The cross-sectional area of the beam is 2.5×10^{-6} m^2.

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(i) Show that the number of photons incident on the mirror per unit time is $1.4 \times 10^{15} s^{-1}$.

[2]

(ii) Use the information in **(b)(i)** to determine the pressure exerted by the light beam on the mirror.

pressure = ... Pa [3]

(c) The beam of red light in **(b)** is now replaced with a beam of blue light of the same intensity.

Suggest and explain whether the pressure exerted on the mirror by the beam of blue light is less than, the same as, or greater than the pressure exerted by the beam of red light.

.....

.....

.....

..... [2]

[Total: 10]

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2. Nov/2023/Paper_9702/42/No.8

(a) State what is meant by a photon.

.....

.....

..... [2]

(b) When the surface of a metal plate is illuminated with electromagnetic radiation, electrons are sometimes emitted from the metal.

(i) State the name of this phenomenon.

..... [1]

(ii) It is observed that this phenomenon occurs only when the frequency of the electromagnetic radiation is greater than a certain minimum value, regardless of the intensity of the radiation.

Explain how this observation provides evidence for the existence of photons.

.....

.....

.....

.....

..... [3]

(c) Fig. 8.1 shows the variation of the maximum kinetic energy of the emitted electrons in **(b)** with the frequency of the incident radiation.

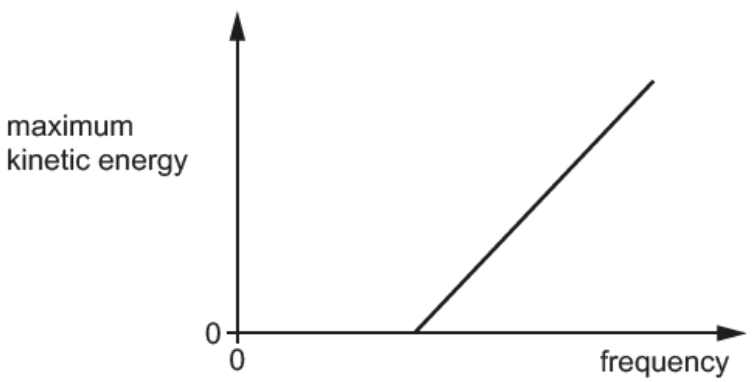


Fig. 8.1

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State the name of the quantity represented by:

(i) the gradient of the line in Fig. 8.1

..... [1]

(ii) the *y*-intercept of the extrapolated line in Fig. 8.1.

..... [1]

[Total: 8]

3. June/2023/Paper_9702/41/No.7

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

.....

..... [1]

(b) Fig. 7.1 shows a glass tube in which electrons are accelerated through a high p.d. to form a beam that is incident on a thin graphite crystal.

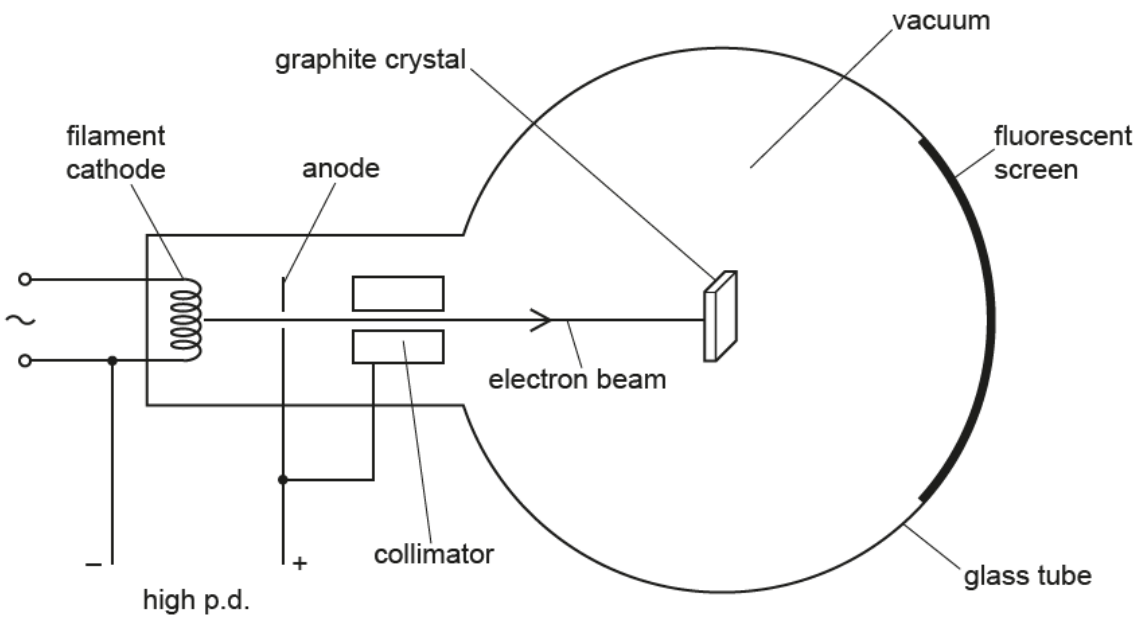


Fig. 7.1 (not to scale)

After passing through the graphite crystal, the electrons reach the fluorescent screen. The screen glows where the electrons strike it.

Fig. 7.2 shows the fluorescent screen viewed end-on, from the right-hand side of Fig. 7.1.

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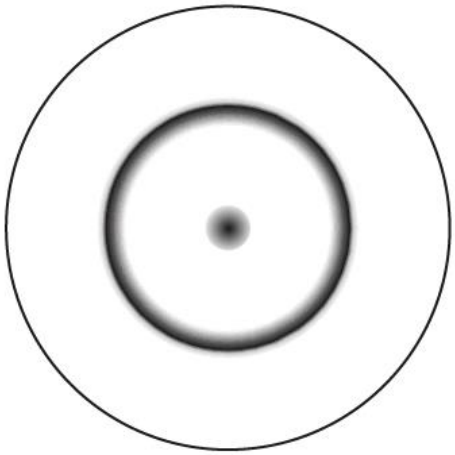


Fig. 7.2

(i) State the name of the phenomenon demonstrated by the pattern shown in Fig. 7.2.

..... [1]

(ii) Explain what can be concluded from the pattern in Fig. 7.2 about the nature of electrons.

.....

.....

..... [2]

(c) The electrons in **(b)** are now accelerated through a greater potential difference between the cathode and the anode.

(i) On Fig. 7.3, sketch the pattern that is now seen on the fluorescent screen in Fig. 7.1.

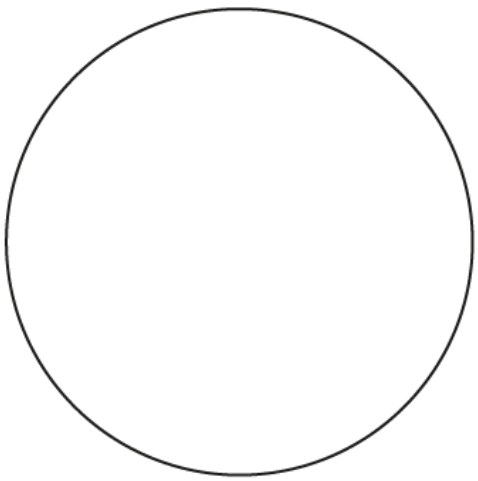


Fig. 7.3

[2]

(ii) Explain, with reference to de Broglie wavelength, the change in the pattern on the fluorescent screen.

.....

.....

.....

.....

..... [3]

[Total: 9]

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4. June/2023/Paper_9702/42/No.8

Fig. 8.1 shows the lowest four energy levels of an electron in an isolated atom.

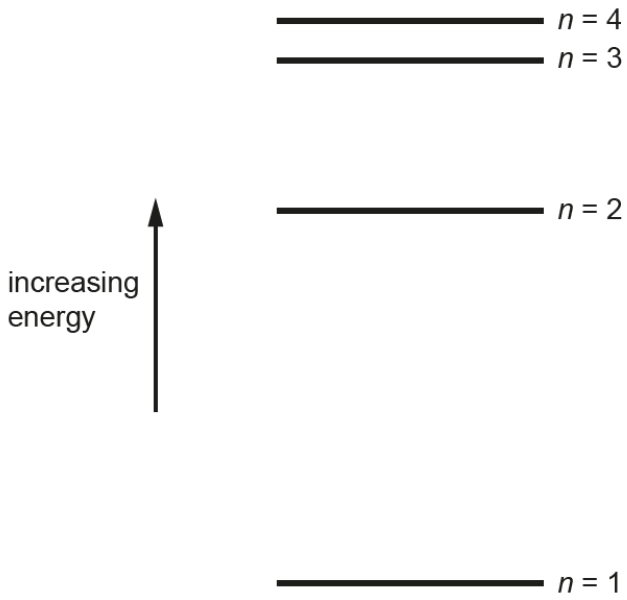


Fig. 8.1

Fig. 8.2 shows the lines in the emission spectrum of the atom that correspond to the transitions of the electron from $n = 3$ to $n = 1$ and from $n = 4$ to $n = 1$.

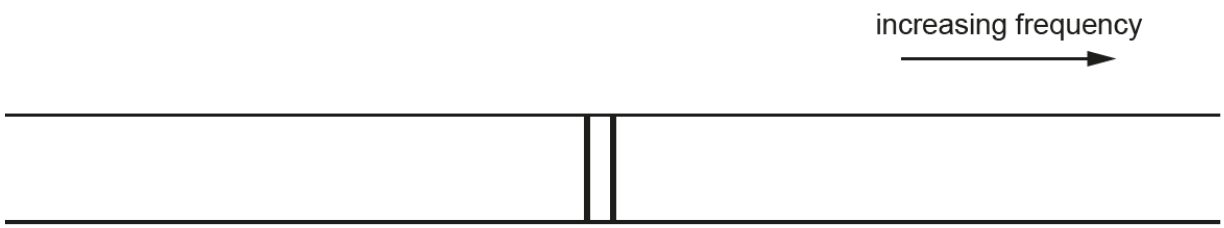


Fig. 8.2

(a) Explain, with reference to photons, why there is a single frequency of electromagnetic radiation that corresponds to each of these transitions.

.....

.....

..... [2]

(b) **(i)** On Fig. 8.2, draw a line that corresponds to the transition of the electron from $n = 2$ to $n = 1$. Label this line A. [2]

(ii) On Fig. 8.2, draw a line that corresponds to the transition of the electron from $n = 3$ to $n = 2$. Label this line B. [2]

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(c) The frequency of radiation represented by line A is f_A.
The frequency of radiation represented by line B is f_B.
The energy of the ground state ($n = 1$) is E_1.

Determine an expression, in terms of f_A, f_B, E_1 and the Planck constant h, for the energy E_3 of the energy level $n = 3$.

E_3 = ... [2]

[Total: 8]

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5. March/2023/Paper_9702/42/No.7

(a) A beam of white light passes through a cloud of cool gas. The spectrum of the transmitted light is viewed and contains a number of dark lines.

Explain why these dark lines occur.

.....

.....

.....

.....

.....

.....

.....

.....

..... [4]

(b) Some energy levels for the electron in an isolated hydrogen atom are illustrated in Fig. 7.1.

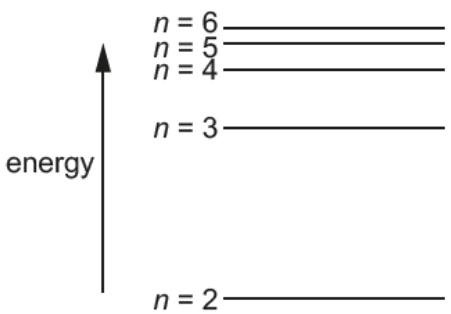


Fig. 7.1

Table 7.1 shows the wavelengths of photons that are emitted in the transitions to $n = 2$ from the other energy levels shown in Fig. 7.1.

Table 7.1

wavelength / nm
412
435
488
658

The energy associated with the energy level $n = 2$ is $-3.40\,\text{eV}$.

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Calculate the energy, in J, of energy level $n = 3$.

energy = ... J [3]

[Total: 7]

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