UMUTECH

150 pages of Particles, Quantum Phenomena an Electricity.

1. (a) How many protons, neutrons and electrons are there in an atom of ${}^{14}_{6}C$?

.... protons

.... neutrons

.... electrons

(2)

(b) The ${}^{14}_{6}C$ atom loses two electrons.
For the ion formed;

(i) calculate its charge in C,

....

(ii) state the number of nucleons it contains,

....

(iii) calculate the ratio $\frac{\text{charge}}{\text{mass}}$ in C kg^{-1}.

....

....

....

....

(4)
(Total 6 marks)

2. (a) (i) Determine the charge, in C, of a ${}^{239}_{92}U$ nucleus.

....

....

(ii) A positive ion with a $^{239}_{92}\text{U}$ nucleus has a charge of 4.80×10^{-19} C. Determine how many electrons are in this ion.

....

....

....

(4)

(b) A $^{239}_{92}\text{U}$ nucleus may decay by emitting **two** β^- particles to form a plutonium nucleus $^{X}_{Y}\text{Pu}$. State what X and Y represent and give the numerical value of each.

X ....

....

Y ....

....

(4)
(Total 8 marks)

3. (a) A stable atom contains 28 nucleons.

Write down a possible number of protons, neutrons and electrons contained in the atom.

.... protons

.... neutrons

.... electrons

(2)

(b) An unstable *isotope* of uranium may split into a caesium nucleus, a rubidium nucleus and four neutrons in the following process.

$$^{236}_{92}\text{U} \Rightarrow {}^{137}_{55}\text{Cs} + {}^{X}_{37}\text{Rb} + 4\,^{1}_{0}\text{n}$$

(i) Explain what is meant by isotopes.

....

....

....

(ii) How many neutrons are there in the $^{137}_{55}$Cs nucleus?

....

(iii) Calculate the ratio $\frac{\text{charge}}{\text{mass}}$, in C kg^{-1}, for the $^{236}_{92}$U nucleus.

....

....

....

(iv) Determine the value of X for the rubidium nucleus.

....

X = ...

(6)

(Total 8 marks)

4. (a) What are isotopes?

....

....

....

....

....

(2)

(b) One of the isotopes of nitrogen may be represented by ${}^{15}_{7}N$.

(i) State the number of each type of particle in its nucleus.

....

....

(ii) Determine the ratio $\frac{\text{charge}}{\text{mass}}$, in C kg^{-1}, of its nucleus.

....

....

....

....

(4)

(c) (i) What is the charge, in C, of an atom of ${}^{15}_{7}N$ from which a single electron has been removed?

....

(ii) What name is used to describe an atom from which an electron has been removed?

....

(2)

(Total 8 marks)

5. (a) Name the constituent of an atom which

(i) has zero charge,

....

(ii) has the largest charge to mass ratio,

....

(iii) when removed leaves a different isotope of the element.

....

(3)

(b) An α particle is the same as a nucleus of helium, $^{4}_{2}\mathrm{He}$.
The equation

$$^{229}_{90}\mathrm{Th} \longrightarrow \, ^{X}_{Y}\mathrm{Ra} + \alpha$$

represents the decay of thorium by the emission of an α particle.

Determine

(i) the values of X and Y, shown in the equation,

X = ...

Y = ...

(ii) the ratio $\dfrac{\text{mass of } ^{X}_{Y}\text{Ra nucleus}}{\text{mass of } \alpha \text{ particle}}$

....

....

....

(3)
(Total 6 marks)

6. (a) The most abundant isotope of cobalt is represented by $^{59}_{27}\text{Co}$.

How many protons, neutrons and orbital electrons are there in a neutral atom of this element?

.... protons

.... neutrons

.... electrons

(2)

(b) How is the nuclide that has one less proton than the nickel nuclide, $^{61}_{28}\text{Ni}$, represented?

....

(2)

(c) (i) The heaviest isotope of hydrogen, whose nucleon number is 3, is called tritium. How is tritium represented?

....

(ii) Calculate the charge per unit mass, in C kg^{-1}, for a tritium nucleus.

....

....

....

(3)
(Total 7 marks)

7. A neutral atom of carbon is represented by $^{14}_{6}\text{C}$.

(i) Name the constituents of this atom and state how many of each are present.

....

....

....

(ii) Which constituent of an atom has the largest charge-to-mass ratio?

....

(iii) Carbon has several isotopes. Explain the term *isotope*.

....

....

(Total 6 marks)

8. (a) (i) Name a force which acts between an up quark, u, and an electron. Explain, with reference to an exchange particle, how this force operates.

You may be awarded marks for the quality of written communication in your answer.

....

....

....

....

....

....

....

....

(ii) With what particle must a proton collide to be annihilated?

....

(4)

(b) A sigma plus particle, Σ^+, is a baryon.

(i) How many quarks does the Σ^+ contain?

....

(ii) If one of these quarks is an s quark, by what interaction will it decay?

....

(iii) Which baryon will the Σ^+ eventually decay into?

....

(3)

(Total 7marks)

9. A particle accelerator is designed to accelerate antiprotons through a potential difference of 2.0 GV and make them collide with protons of equal energy moving in the opposite direction. In such a collision, a proton-antiproton pair is created as represented by the equation

$$p + \bar{p} \rightarrow p + \bar{p} + p + \bar{p}$$

You may assume that the rest energy of the proton is 940 MeV.

(a) State how an antiproton differs from a proton.

....

....

(1)

(b) Give the total kinetic energy of the particles, in GeV, before collision.

....

(1)

(c) State the rest energy of the antiproton.

....

(1)

(d) Calculate the total kinetic energy of the particles, in GeV, after the collision.

....

....

....

....

(3)
(Total 6 marks)

10. Some subatomic particles are classified as *hadrons.*

(a) What distinguishes a hadron from other subatomic particles?

....

....

(1)

(b) Hadrons fall into two subgroups. Name each subgroup and describe the general structure of each.

subgroup 1 ....

....

subgroup 2 ....

....

(3)

(c) The following equation represents an event in which a positive muon collides with a neutron to produce a proton and an antineutrino.

$$n + \mu^{+} \Rightarrow p + \bar{\nu}_{\mu}.$$

Show that this equation obeys the conservation laws of charge, lepton number and baryon number.

....

....

....

(3)

(Total 7 marks)

11. (a) (i) Underline the particles in the following list that may be affected by the weak interaction.

positron neutron photon neutrino positive pion

(ii) Underline the particles in the following list that may be affected by the electromagnetic force.

electron antineutrino proton neutral pion negative muon

(4)

(b) A positive muon may decay in the following way,

$$\mu^{+} \Rightarrow e^{+} + \nu_{e} + \bar{\nu}_{\mu}$$

(i) Exchange each particle for its corresponding antiparticle and complete the equation to show how a negative muon may decay.

$$\mu^{-} \Rightarrow$$

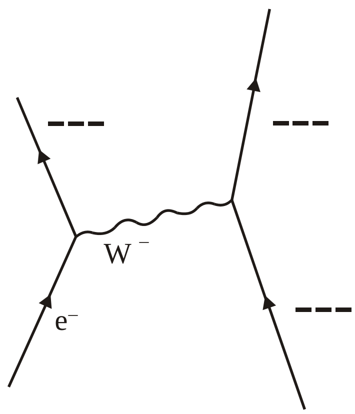
(ii) Give **one** difference and **one** similarity between a negative muon and an electron.

difference ....

similarity ....

(3)

(c) Complete the Feynman diagram, which represents electron capture, by labelling all the particles involved.



(3)
(Total 10 marks)

12. A carbon-14 nucleus undergoes β^- decay, forming a new nucleus, releasing a β^- particle and one other particle which is difficult to detect.

(a) Write down the proton number and the nucleon number of the new nucleus.

proton number ....

nucleon number ....

(b) Name the particle which is difficult to detect.

....

(c) Name the baryons and leptons involved in the decay.

baryons ....

(d) Give the quark structure for the neutron and the proton.

neutron ....

proton ....

Hence state the quark transformation that occurs during β^- decay.

....

(Total 7 marks)

13. (a) State which interaction, strong or weak, is experienced by each of the following particles.

hadrons: ....

leptons: ....

(2)

(b) Give **one** example of a hadron and **one** example of a lepton.

hadron: ....

lepton: ....

(2)

(c) Hadrons are classified as either baryons or mesons. How many quarks are there in a baryon and in a meson?

baryon: ....

meson: ....

(2)

(d) (i) State the quark composition of a neutron.

....

(ii) Describe, in terms of quarks, the process of β^- decay when a neutron changes into a proton.

....

....

....

(iii) Sketch a Feynman diagram to represent β^- decay.

(4)
(Total 10 marks)

14. (a) (i) What class of particle is represented by the combination of three antiquarks, $\bar{q}\bar{q}\bar{q}$?

....

(ii) Name a hadron that has an antiparticle identical to itself.

....

(3)

(b) The kaon K^+ has a strangeness of +1.

(i) Give its quark composition.

....

(ii) The K^+ may decay via the process

$$K^+ \rightarrow \pi^+ + \pi^0.$$

State the interaction responsible for this decay.

....

(iii) The K^+ may also decay via the process

$$K^+ \rightarrow \mu^+ + \nu_\mu.$$

Change each particle in this equation to its corresponding antiparticle in order to complete an allowed decay process for the negative kaon K^-.

$$K^- \rightarrow$$

(iv) Into what class of particle can both the μ^+ and the ν_μ be placed?

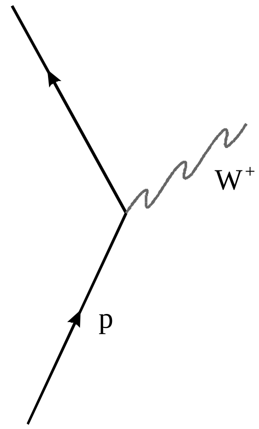
....

(v) State **one** difference between a positive muon, μ^+, and a positron, e^+.

....

(6)

(c) The figure below shows a partially completed Feynman diagram of β^+ decay.



Complete the figure and label all the particles involved.

(3)
(Total 12 marks)

15. (a) The negative kaon, K^-, has a strangeness of –1.
Write down its quark composition.

....

(2)

(b) The kaon, K^- may decay into a muon and an antineutrino in the following way:

$$K^- \rightarrow \mu^- + \bar{\nu}_\mu .$$

(i) Complete the following table using ticks and crosses as indicated in the first row.

	K^-	μ^-	$\bar{\nu}_\mu$
charged particle	✓	✓	✗
hadron			
meson			
baryon			

lepton			

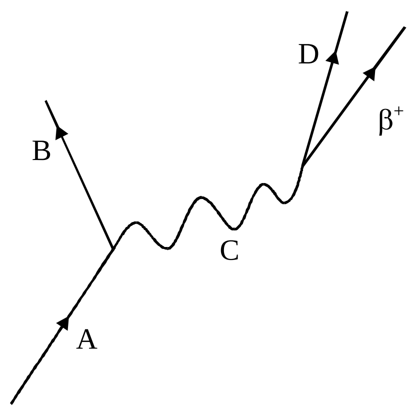
(ii) In the decay shown above, charge is conserved. Give another quantity that is conserved and a quantity that is not conserved in the decay of K^-.

quantity conserved ....

quantity not conserved ....

(6)

(c) The Feynman diagram below represents the β^+ decay process.



(i) What quantity changes continuously in moving from the bottom to the top of the diagram?

....

(ii) Name the particles represented by the letters A to D.

A ....

B ....

C ....

D ....

(iii) What type of interaction is responsible for β^+ decay?

....

(6)
(Total 14 marks)

16. (i) Name **two** hadrons.

....

....

(ii) Name **two** leptons which are also antiparticles.

....

....

(iii) State a possible quark structure of the pion π^0.
A table of the properties of quarks is given in the Data Sheet.

....

(iv) A K^- kaon is a strange particle.
State **one** characteristic of a strange particle.

....

....

(Total 4 marks)

17. (a) When monochromatic light is incident on a particular metal plate, electrons are emitted. The intensity of the light is then increased.

Explain

(i) why the maximum kinetic energy of the emitted electrons does **not** change,

....

(ii) why the number of electrons emitted per second increases.

....

....

....

....

(3)

(b) A potassium metal plate is illuminated with incident light of wavelength 5.10×10^{-7} m. The work function of potassium is $3.5\ 8 \times 10^{-19}$ J.

(i) Show that the frequency of the incident light is approximately 6×10^{14} Hz.

....

....

....

(ii) Calculate the energy, in J, of an incident photon.

....

....

....

(iii) Calculate the maximum kinetic energy, in J, of an emitted electron.

....

....

....

....

(iv) The table gives the work function of four metals.

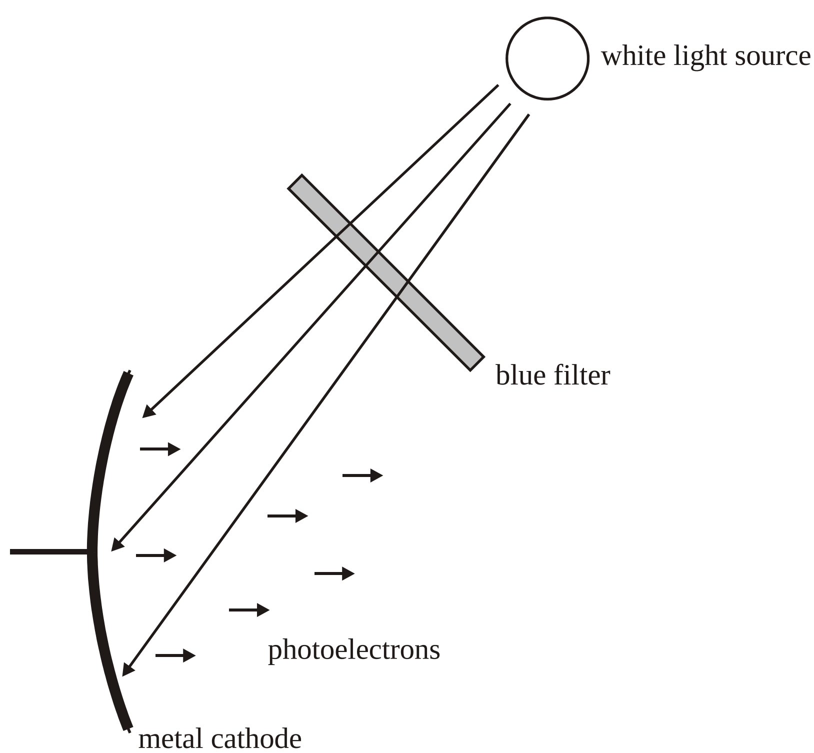
metal	work function / J × 10^{-19}
caesium	3.04
silver	7.57
sodium	3.94
tungsten	7.33

Which of these metals would emit electrons when illuminated with light of wavelength 5.10×10^{-7} m?

....

(7)
(Total 10 marks)

18. The apparatus shown in the figure below can be used to demonstrate the photoelectric effect. Photoelectrons are emitted from the metal cathode when it is illuminated with white light which has passed through a blue filter.



You may be awarded additional marks to those shown in brackets for the quality of written communication in your answers to parts (a) and (b).

(a) The intensity of the light source is reduced. State and explain the effect of this on the emitted photoelectrons.

....

....

....

....

(3)

(b) Explain why no photoelectrons are emitted when the blue filter is replaced by a red filter.

....

....

....

....

(3)

(c) When a metal of work function 2.30×10^{-19} J is illuminated with ultraviolet radiation of wavelength 200 nm, photoelectrons are emitted.

Calculate

(i) the frequency of the ultraviolet radiation,

....

....

(ii) the threshold frequency of the metal,

....

(iii) the maximum kinetic energy of the photoelectrons, in J.

....

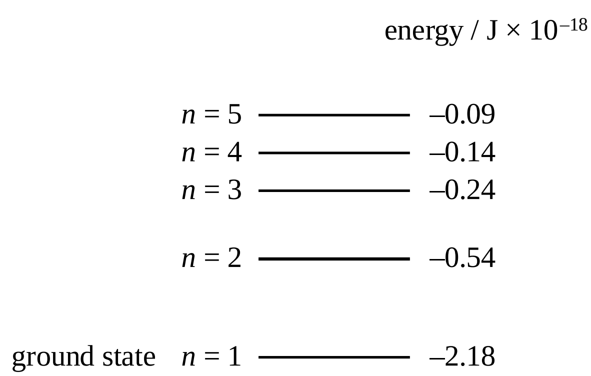
....

....

....

(5)
(Total 11 marks)

19. The lowest energy levels of a hydrogen atom are represented in the diagram below, which is **not** to scale.



(i) Describe what happens when a hydrogen atom is ionised.

....

....

(ii) State the minimum amount of energy, in J, required to ionise a hydrogen atom from its ground state.

....

(iii) A hydrogen atom excited to the $n = 3$ energy level may emit either a single photon or two photons in returning to the ground state.

Describe what happens to the electron in each case.

....

....

....

....

....

....

....

(iv) Use the diagram above to identify the transition which produces a photon of energy 2.09×10^{-18} J.

....

(v) Calculate the frequency of an emitted photon due to a transition from level $n = 2$ to the ground state.

....

....

....

(Total 8 marks)

20. (a) When monochromatic light is incident on a metal plate, electrons are emitted only when the frequency of the light exceeds a certain threshold frequency. Explain, in terms of energy, why this threshold frequency exists.

....

....

....

....

....

(3)

(b) A sodium metal surface is illuminated with incident light of frequency 9.70×10^{14} Hz. The maximum kinetic energy of an emitted electron is 2.49×10^{-19} J.

Calculate

(i) the wavelength of the incident light,

....

....

(ii) the energy, in J, of each incident photon,

....

....

(iii) the work function, in J, of sodium,

....

....

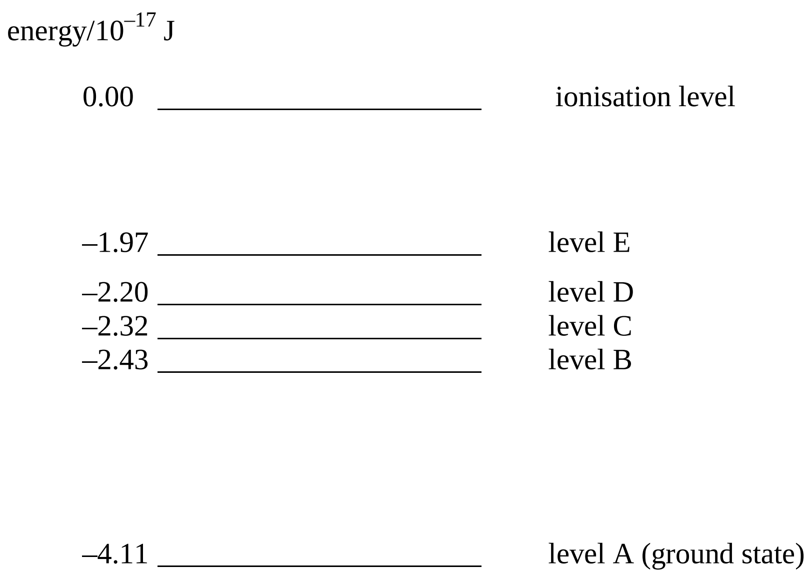
(iv) the work function, in eV, of sodium.

....

....

(7)
(Total 10 marks)

21. Some of the energy levels of an atom are shown below. The atom may be *ionised* by electron impact.



(a) (i) State what is meant by the ionisation of an atom.

....

....

(ii) Calculate the minimum kinetic energy, in eV, of an incident electron that could ionise the atom from its ground state.

....

....

(2)

(b) You may be awarded marks for the quality of written communication in your answer to parts (b)(i) and (b)(ii).

The atom in the ground state is given 5.00×10^{-17} J of energy by electron impact.

(i) State what happens to this energy.

....

....

(ii) Describe and explain what could happen subsequently to the electrons in the higher energy levels.

....

....

....

....

....

(4)

(c) Identify **two** transitions between energy levels that would give off electromagnetic radiation of the same frequency.

__________ to __________

and

__________ to __________

(2)
(Total 8 marks)

22. (a) Calculate the wavelength of a γ-ray photon which has an energy of 1.6×10^{-15} J.

....

....

(b) An X-ray photon is generated which has the same energy as the γ-ray photon described in part (a).

(i) How do the speeds in a vacuum of these two photons compare?

....

(ii) How do their abilities to penetrate a given material compare?

....

(2)

(Total 4 marks)

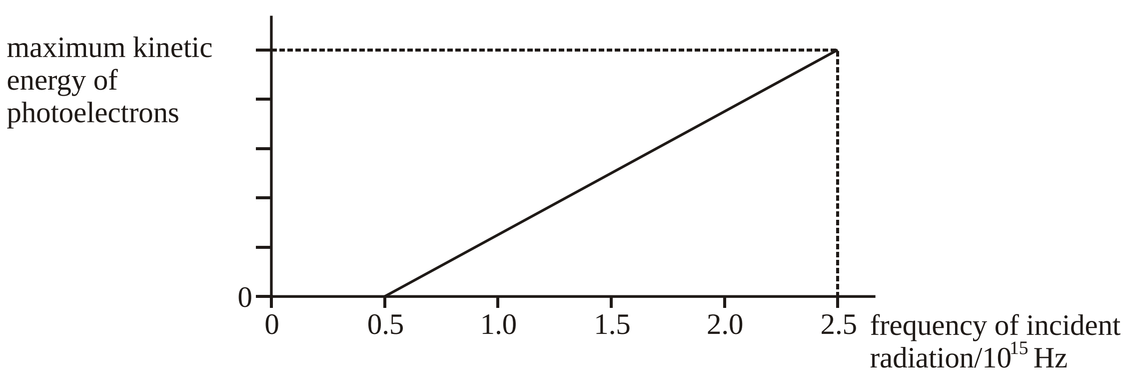
23. (a) Explain what is meant by the term *work function* of a metal.

....

....

(2)

(b) In an experiment on the photoelectric effect, the maximum kinetic energy of the emitted photoelectrons is measured over a range of incident light frequencies. The results obtained are shown in the figure below.



(i) A metal of work function φ is illuminated with light of frequency f. Write down the equation giving the maximum kinetic energy, E_K, of the photoelectrons emitted in terms of φ and f.

$E_K =$

(ii) Use the data in the figure to determine the work function of the metal.

....

....

....

....

(iii) Determine the maximum kinetic energy of the photoelectrons when the frequency of the incident radiation is 2.5×10^{15} Hz.

....

....

....

....

(6)

(c) The experiment is repeated but with the light incident on a metal of lower work function. Draw a new line on the figure that results from this change.

(2)

(Total 10 marks)

24. (a) In the photoelectric effect equation

$$hf = \phi + E_k$$

state what is meant by

hf ....

....

ϕ ....

....

E_k ....

....

(3)

(b) Monochromatic light of wavelength 3.80×10^{-7} m falls with an intensity of 6.0 μW m^{-2} on to a metallic surface whose work function is 3.2×10^{-19} J.
Using data from the *Data Sheet*, calculate

(i) the energy of a single photon of light of this wavelength,

....

....

....

(ii) the number of photons emitted per second from 1.0×10^{-6} m^2 of the surface if a photon has a 1 in 1000 chance of ejecting an electron,

....

....

....

....

....

(iii) the maximum kinetic energy which one of these photoelectrons could possess.

....

....

....

(5)
(Total 8 marks)

25. (i) Calculate the de Broglie wavelength of an electron travelling at 2.00% of the speed of light.

....

....

....

....

(ii) Determine the frequency of the electromagnetic radiation that would have the same wavelength as this electron.

....

....

....

....

(Total 5 marks)

26. Electrons may be emitted when electromagnetic radiation is incident on a metallic surface

(a) The photoelectric equation is

$$hf = \phi + E\ ,$$

where h is the Planck constant and f is the frequency of the incident radiation.

Explain the meanings of

work function, ϕ ....

....

E ....

....

(2)

(b) In a typical experiment to investigate the photoelectric effect, E was measured for photons of different wavelengths, λ,and the values in the table were obtained.

λ/nm	200	300	400	500	600
E $^{-19}$ /J	6.72	3.30	1.68	0.66	0.05
$\frac{1}{\lambda}$ / nm^{-1}					

(i) By rearranging the photoelectric equation, show that a graph of E (y-axis) plotted against $\frac{1}{\lambda}$ (x-axis) will give a straight line.

....

....

....

(ii) Use the above data to plot this graph and use your graph to determine values for ϕ, in eV, and the Planck constant, h.

....

....

....

....

....

(Allow one sheet of graph paper)

(9)

(c) Using the same axes, sketch the graph which you would expect to obtain if the experiment were repeated with a metal having a larger value of ϕ

(2)

(d) In a simple demonstration of the photoelectric effect, a metal plate is given a negative charge and illuminated with, in turn,

(i) red light from a laser,

(ii) an ultraviolet lamp.

The ultraviolet lamp causes the plate to lose charge but the laser has no effect. Explain why this is so.

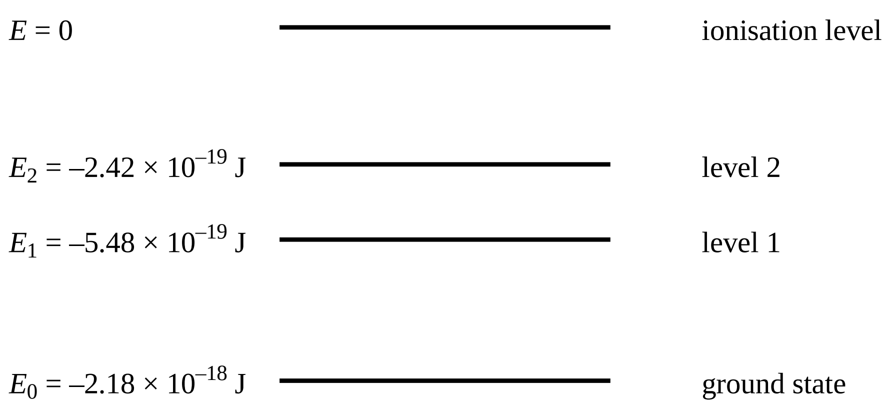
....

....

....

(2)
(Total 15 marks)

27.



The diagram represents some of the energy levels of an isolated atom. An electron with a kinetic energy of 2.0×10^{-18} J makes an inelastic collision with an atom in the ground state.

(a) Calculate the speed of the electron just before the collision.

....

....

....

(2)

(b) (i) Show that the electron can excite the atom to level 2.

....

....

....

(ii) Calculate the wavelength of the radiation that will result when an atom in level 2 falls to level 1 and state the region of the spectrum to which this radiation belongs.

....

....

....

....

....

(6)

(c) Calculate the minimum potential difference through which an electron must be accelerated from rest in order to be able to ionise an atom in its ground state with the above energy level structure.

....

....

....

(2)

(Total 10 marks)

28. Some energy levels of an atom of a gas are shown in **Figure 1**.

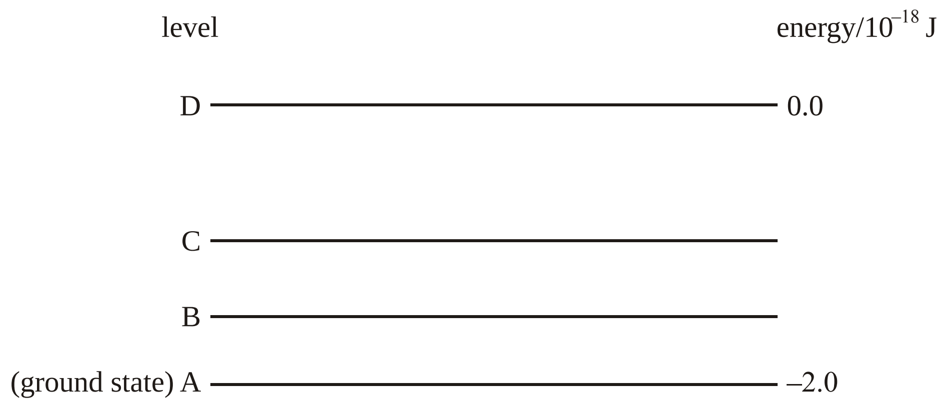


Figure 1

When a current is passed through the gas at low pressure, a line spectrum is produced. Two of these lines, which correspond to transitions from levels B and C respectively to the ground state, are shown in **Figure 2**.

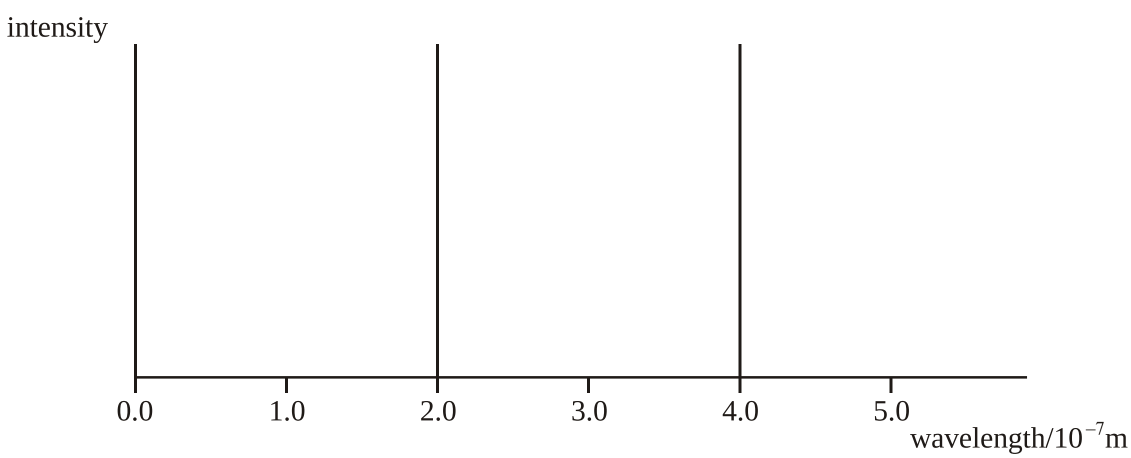


Figure 2

(a) Describe what happens to an electron in an atom in the ground state in order for the atom to emit light of wavelength 4.0×10^{-7} m.

You may be awarded marks for the quality of written communication in your answer.

....

....

....

....

....

....

(3)

(b) Determine the energy, in J, of

(i) the photons responsible for each of the two lines shown in **Figure 2**,

....

....

....

....

....

(ii) levels B and C in **Figure 1.**

....

....

....

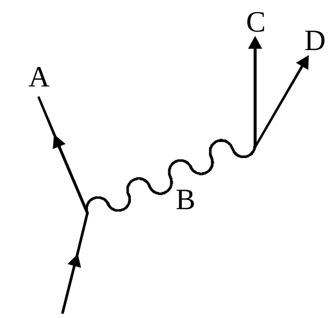
energy of level B = ...

energy of level C = ...

(5)
(Total 8 marks)

29. (a) A positron is emitted from a nucleus when a proton changes to a neutron in the nucleus. The Feynman diagram for this process is shown in the figure below.

Identify the particles labelled A, B, C and D in the diagram.



particle A ....

particle B ....

particle C ....

particle D ....

(b) Name an exchange particle of the weak nuclear force.

....

(c) State **one** difference between the photon and the exchange particle of the weak nuclear force.

....

(Total 7 marks)

30. (a) Calculate the speed of electrons which have a de Broglie wavelength of 1.5×10^{-10} m.

....

....

....

(2)

(b) Would you expect the electrons in part (a) to be diffracted by crystals in which the atom spacing is 0.10 nm? Explain your answer.

....

....

(2)
(Total 4 marks)

31. Light is emitted when the vapour of an element is bombarded by energetic electrons. The spectrum of the light emitted contains lines, each of a definite wavelength.

(a) Explain how energetic electrons cause the atoms of the vapour of an element to emit light.

....

....

....

(3)

(b) How does the existence in the spectrum of lines of a definite wavelength support the view that atoms have discrete energy levels?

....

....

....

(2)
(Total 5 marks)

32. (a) (i) Explain what is meant by the *duality* of electrons.

....

....

(ii) State the relation between the electron mass, electron velocity and the wavelength for a monoenergetic beam of electrons.

....

....

....

(3)

(b) The spacing of atoms in a crystal is 1.0×10^{-10} m.

mass of the electron = 9.1×10^{-31} kg
the Planck constant = 6.6×10^{-34} J s

Estimate the speed of electrons which would give detectable diffraction effects with such crystals.

....

....

....

(4)

(c) Give **one** piece of evidence to demonstrate that electrons have particle properties.

....

....

(1)
(Total 8 marks)

33. Use data from the Data Sheet in this question.

(a) (i) Define the *electronvolt.*

....

....

(ii) Show that the speed of an electron accelerated through a potential difference of 6.0kV is 4.6×10^7 m s^{-1}.

....

....

....

....

(4)

(b) State what is meant by the duality of the nature of electrons.

....

....

....

(1)

(Total 5 marks)

Answers

1. (a) 6 (protons) and 6 (electrons) **(1)**
8 (neutrons) **(1)** 2

(b) (i) $(2 \times 1.6 \times 10^{-19}) = 3.2 \times 10^{-19}$ (C) **(1)**

(ii) 14 **(1)**

(iii) $m = 14 \times 1.67 \times 10^{-27}$ (kg) **(1)**

$$\frac{Q}{m} = \left(\frac{3.2\times10^{-19}}{14\times1.67\times10^{-27}}\right) = 1.4 \times 10^{7}\ (\text{C kg}^{-1})$$ **(1)** (1.37×10^{7} (C kg^{-1}))

(allow C.E for values from (i) and (ii)) 4

[6]

2. (a) (i) (charge) $= 92 \times 1.60 \times 10^{-19}$
$= 1.47 \times 10^{-17}$ (C) **(1)**

(ii) (magnitude of ion charge) = 3(*e*) **(1)**
number of electrons (= 92 – 3) = 89 **(1)** 4

(b) X: number of nucleons [or number of neutrons plus protons or mass number] **(1)**
239 **(1)**
Y: number of protons [or atomic number] **(1)**
94 **(1)** 4

[8]

3. (a) number of protons = number of electrons (e.g.14) **(1)**
number of protons + number of neutrons = 28 **(1)** 2

(b) (i) nuclei with the same number of protons **(1)**
but different number of neutrons/nucleons **(1)**

(ii) (137 – 55) = 82 **(1)**

(iii) $\frac{Q}{m} = \frac{92 \times 1.60 \times 10^{-19}}{236 \times 1.67 \times 10^{-27}}$ **(1)**
$= 3.73 \times 10^{7}$ (C kg^{-1}) **(1)**

(iv) X (= 236 – 137 – 4) = 95 **(1)** 6

[8]

4. (a) (atoms with) same number of protons/same atomic number **(1)**
different number of neutrons/mass number/ nucleons **(1)** 2

(b) (i) 7 protons **(1)**
8 neutrons **(1)**

(ii) $\left(\frac{\text{charge}}{\text{mass}}\right) = \frac{7 \times 1.6 \times 10^{-19}}{15 \times 1.67 \times 10^{-27}}$ **(1)**
$= 4.5 \times 10^{7}$ (C kg^{-1}) **(1)** (4.47×10^{7} (C kg^{-1})) 4
(allow C.E. for incorrect values in (b) (i))

(c) (i) (+) 1.6×10^{-19} (C) **(1)**

(ii) positive ion **(1)** 2

[8]

5. (a) (i) neutron **(1)**

(ii) electron **(1)**

(iii) neutron **(1)** 3

(b) (i) (X =) 225 **(1)**
(Y =) 88 **(1)**

(ii) $\left(\frac{\text{mass of } {}^{225}_{88}\text{Ra}}{\text{mass of } \alpha \text{ particle}} = \frac{225}{4}\right)$ = 56(.3) **(1)**

(allow C.E. for value of X from (i)) 3

[6]

6. (a) 27 (protons) and 27 (electrons) **(1)**
32 (neutrons) **(1)** 2

(b) ${}^{60}_{27}\text{Co}$ **(2)**

(correct nucleon number **(1)** correct symbol and proton number **(1)**) 2

(c) (i) ${}^{3}_{1}\text{H}$ (or ${}^{3}_{1}\text{T}$) **(1)**

(ii) charge/unit mass = $\frac{1.60\times10^{-19}}{3\times1.67\times10^{-27}}$ [or $\frac{1}{3}$ e/m_p) **(1)**

= 3.19×10^{7} (C kg^{-1}) **(1)** (allow C.E. from (i)) 3

[7]

7. (i) protons and neutrons **(1)**
6p , 8n / **(1)**
[**o**r u and d quarks **(1)**, 20u and 22d **(1)**]
6 electrons **(1)**

(ii) electron **(1)**

(iii) atoms with identical numbers of protons but different numbers of neutrons **(1)** 6

[6]

8. (a) (i) (named force) from weak (nuclear), electromagnetic or gravity **(1)**
uses a mediating/exchange particle, named particle from $W^{(\pm)}$ (boson), (γ) photon or graviton **(1)**
to transfer energy/momentum **(1)**
when electron emits/receives exchange particle, disappearance/creation of new particle occurs **(1)**
QWC 1

(ii) anti proton **(1)**

max 4

(b) (i) 3 (quarks) **(1)**

(ii) weak (nuclear) **(1)**

(iii) proton **(1)** 3

[7]

9. (a) proton is positively charged, antiproton is negatively charged **(1)** 1

(b) 4.0 (GeV) **(1)** 1

(c) rest energy of antiproton is also 940 MeV **(1)** 1

(d) energy needed to create proton-antiproton pair is 2×940 MeV **(1)** = 1.9 GeV **(1)**
kinetic energy remaining = 4.0 – 1.9 = 2.1 GeV **(1)** 3

[6]

10. (a) hadrons are subject to the strong nuclear force
[or hadrons consist of quarks (or antiquarks)] **(1)** 1

(b) (i) baryons and mesons **(1)**

baryons consist of three quarks
antibaryons consist of three antiquarks
mesons consist of a quark and an antiquark (any two) **(1)** **(1)** 3

(c) Q: 0 + 1 = 1 + 0 **(1)**
L: 0 – 1 = 0 – 1 **(1)**
B: 1 + 0 = 1 + 0 **(1)** 3

[7]

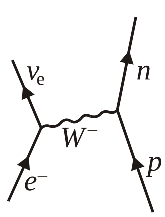
11. (a) (i) positron, neutron, neutrino, positive pion **(1)** **(1)** (if all correct)
(lose **(1)** for each error)

(ii) electron, proton, negative muon **(1)** **(1)** (if all correct)
(lose **(1)** for each error) 4

(b) (i) $(\mu^-) \rightarrow e^- + \overline{\nu_e} + \nu_\mu$ **(1)**

(ii) difference: mass or half-life or generation of lepton **(1)**
similarity: both leptons or both negatively charged **(1)** 3

(c) 3



ν_e **(1)**
n **(1)**
p **(1)**

[10]

12. (a) 7,14 **(1)**

(b) (anti) neutrino **(1)**

(c) proton, neutron **(1)**
electron, (anti) neutrino **(1)**

(d) udd **(1)**
uud **(1)**
d → u **(1)**

[7]

13. (a) hadrons interact through the strong interaction **(1)**
leptons interact through the weak interaction **(1)** 2

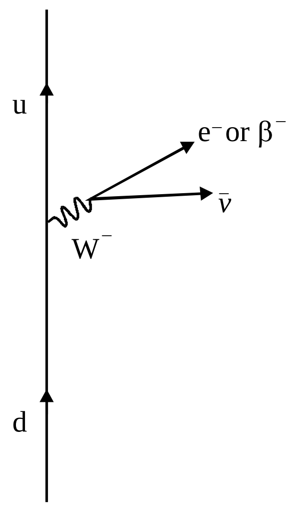
(b) hadron example **(1)**
lepton example**(1)** 2

(c) baryon = 3 quarks (or antiquarks) **(1)**
meson = quark +antiquark **(1)** 2

(d) (i) udd **(1)**

(ii) d changes to u **(1)**

(iii) W^- emitted **(1)**
W^- decays to electron and antineutrino **(1)**
(both correctly shown on Feynman diagram) **(1)** 4



[10]

14. (a) (i) anti **(1)** baryon **(1)** (hadron, one mark only)

(ii) $\pi°$ [or $\eta°$] **(1)** 3

(b) (i) $u\bar{s}$ **(1) (1)** (**(1)** for quark + antiquark)

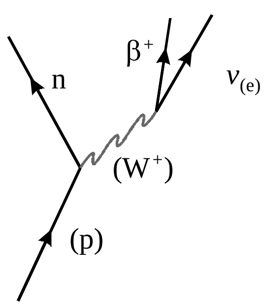
(ii) weak (interaction) **(1)**

(iii) $K^- \rightarrow \mu^- + \nu_\mu$ **(1)**

(iv) lepton **(1)**

(v) mass (or its generation or rest energy or stability) **(1)** 6

(c)



(3) (one mark for each particle) 3

[12]

15. (a) $s\bar{u}$ **(1) (1)**
(for any quark + antiquark combination
or for a one s quark in a two quark combination $_{max}1$) 2

(b) (i)

	K^-	μ^-	ν_μ
charged particle	✓	✓	×
hadron	✓	×	×
meson	✓	×	×
baryon	×	×	×
lepton	×	✓	✓

(1) (1) (1) (1) (one mark for each correct line)

(ii) (conserved) lepton or baryon number or energy or momentum **(1)**
(not conserved) strangeness **(1)** 6

(c) (i) time **(1)**

(ii) A : proton or u quark **(1)**
B : neutron or d quark **(1)**
C : W^+(boson) **(1)**
D : neutrino **(1)**

(iii) weak(interaction) **(1)** 6

[14]

16. (i) any two hadrons e.g. proton, neutron, pion, kaon, etc. **(1)**

(ii) any two antiparticle leptons e.g. e^+, μ^+, anti-(electronic) neutrino etc **(1)**

(iii) $d\bar{d}$ (or $u\bar{u}$ or $\frac{1}{\sqrt{2}}(d\bar{d} + u\bar{u})$)

(iv) usually created in pairs (*)
normally decays into combinations of π, p and n (*)
contains at least one strange quark (*)
usually decays via the weak interaction (*)
half - life is relatively long compared with half -life of typical particle decaying via strong interaction (*)
(*) any one **(1)**

[4]

17. (a) (i) the energy of a photon does not depend on the intensity **(1)**
so electron gains no extra energy
[or the energy is dependent on the wavelength/frequency] **(1)**

(ii) the intensity of the light determines the number of photons per second **(1)**
one photon interacts with one electron
[or hence more interactions with electrons] **(1)** 3

(b) (i) (use of $c = f\lambda$ gives) $f = \dfrac{3.00 \times 10^{8}}{5.10 \times 10^{-7}}$ **(1)**

$= 5.88 \times 10^{14}$ (Hz) **(1)**

(ii) (use of $E = hf$ gives) $E = 6.63 \times 10^{-34} \times 5.88 \times 10^{14}$ **(1)**

(allow C.E. for value of f from (i))

$= 3.9(0) \times 10^{-19}$ (J) **(1)**

(iii) (use of $hf = \phi + E_k$ gives) $3.9 \times 10^{-19} = 3.58 \times 10^{-19} + E_k$ **(1)**
(allow C.E. for value of E from (ii))
$E_k = 3.2 \times 10^{-20}$ (J) **(1)**

(iv) caesium **(1)** (allow C.E. for value of E from (ii)) 7

[10]

18. (a) intensity determines the number of photons per second **(1)**
fewer photoelectrons per second **(1)**
(individual) photon energies are not changed **(1)**
with no change in the (kinetic) energy/speed **(1)**
one photon interacts with one electron **(1)** 3

(b) energy of a photon is proportional to frequency (or $E = hj$) **(1)**
photon of red light has less energy than a photon of blue light
[or/f_{red} </f_{blue} or $\lambda_{red} > \lambda_{blue}$] **(1)**
the energy is insufficient to overcome the work function of the metal
[or the frequency is below the threshold frequency] **(1)** 3

(c) (i) $f\left(=\frac{3.0\times10^{8}}{200\times10^{-9}}\right)=1.5\times10^{15}$ Hz **(1)**

(ii) $f_0\left(=\frac{\phi}{h}\right)=\frac{2.3\times10^{-19}}{6.63\times10^{-34}}$ **(1)**

$=3.5 \times 10^{14}$Hz **(1)**
(3.47×10^{14}Hz)

(iii) (use of $hf = \phi + E_k$ gives)
$E_k\left(6.63\times10^{-34}\times1.5\times10^{15}\right)-2.3\times10^{-19}$ **(1)**

7.6×10^{-19} (J) **(1)**

(7.645×10^{-19}(J)) 5

(allow C.E for value of f from (i))

[11]

19. (i) an electron is removed from the atom **(1)**

(ii) 2.18×10^{-18} (J) **(1)**

(iii) (single photon):electron loses energy [or falls] from level $n = 3$ to $n = 1$ and emits a single photon **(1)**

(two photons): electron falls from level $n = 3$ to $n = 2$, emitting a photon **(1)**
followed by a fall from level $n = 2$ to $n = 1$, emitting another photon **(1)**

QWC

(iv) level n = 5 to the ground state [or $E_5 \rightarrow E_1$] **(1)**

(v) (use of $hf = E_1 - E_5$ gives) $f = \dfrac{(-0.54\times10^{-18} - -2.18\times10^{-18})}{6.63\times10^{-34}}$ **(1)**

$= 2.47 \times 10^{15}$ Hz **(1)** 8

[8]

20. (a) the energy of each photon/the light increases with frequency **(1)**
electrons need a minimum amount of energy to leave the metal **(1)**
this amount of energy is equal to the work function **(1)** 3

QWC

(b) (i) (use of $v = f\lambda$ gives) $\lambda = \dfrac{3.00\times10^{8}}{9.70\times10^{14}}$ **(1)**

$= 3.09 \times 10^{-7}$m **(1)**

(ii) (use of $E = hf$ gives) $E = 6.63 \times 10^{-34} \times 9.70 \times 10^{14}$ **(1)**

$= 6.43 \times 10^{-19}$ (J) **(1)**

(iii) (use of $hf = \phi + E_k$ gives) $6.43 \times 10^{-19} = \phi + 2.49 \times 10^{-19}$ **(1)**
(allow C.E. from (b)(ii))
$\phi = 3.94 \times 10^{-19}$ (J) **(1)**

(iv) $\phi = \left[\frac{3.94\times10^{-19}}{1.60\times10^{-19}}\right]$ = 2.46 (eV) **(1)** (allow C.E. from (b)(iii) 7

[10]

21. (a) (i) when an atom loses an orbiting electron (and becomes charged) **(1)**

(ii) $\frac{4.11\times10^{-17}}{1.6\times10^{-19}} = 260\,(\text{eV})$ **(1)** (257 (eV)) 2

(b) (i) the electron in the ground state leaves the atom **(1)**
with remaining energy as kinetic energy (0.89×10^{-17} J) **(1)**

(ii) the orbiting electrons fall down **(1)**
to fill the vacancy in the lower levels **(1)**
various routes down are possible **(1)**
photons emitted **(1)**
taking away energy **(1)**

Max 4

(c) E to D and D to B **(1)**
both in correct order **(1)** 2

[8]

22. (a) $\lambda\left(=\frac{hc}{E}\right) = \frac{6.63\times10^{-34}\times3\times10^{8}}{1.6\times10^{-15}}$ **(1)**
$= 1.2(4) \times 10^{-10}$ m **(1)** 2

(b) (i) same **(1)**

(ii) same **(1)** 2

[4]

23. (a) minimum (energy/work done) **(1)**
energy required to remove an electron from the surface (of the metal) **(1)** 2

(b) (i) $E_k = hf - \phi$ **(1)**

$f_0 = 0.50 \times 10^{15}$ (Hz) **(1)**

$\phi (= hf_0) = 6.6 \times 10^{-34} \times 0.50 \times 10^{15}$ **(1)**

$= 3.3 \times 10^{-19}$ J **(1)**

(ii) (use of $E_k = hf - \phi$ gives) $E_k = (6.6 \times 10^{-34} \times 2.5 \times 10^{15}) - 3.3 \times 10^{-19}$ **(1)**

$= 1.3(2) \times 10^{-18}$ J **(1)**

(allow C.E. for incorrect value of ϕ from (ii))

[or (using gradient = $h = \Delta E_k/\Delta f$)

$\Delta E_k = 6.6 \times 10^{-34} \times 2 \times 10^{15}$ **(1)**

$= 1.3(2) \times 10^{-18}$ J **(1)**] 6

(c) same gradient **(1)**

drawn above existing line with smaller *x* intercept **(1)** 2

[10]

24. (a) hf = **photon** energy **(1)**

ϕ = work function **(1)**

E_k = **maximum** kinetic energy of photoelectrons **(1)** 3

(b) (i) $E\left(=\dfrac{hc}{\lambda}\right) = \dfrac{6.6\times10^{-34}\times3\times10^{8}}{3.8\times10^{-7}} = 5.23 \times 10^{-19}$ J **(1)**

(ii) energy on surface = 6.0×10^{-12} J mm^{-2} s^{-1} **(1)**

$N = \dfrac{6.0\times10^{-12}}{5.23\times10^{-16}} = 1.1(5) \times 10^{4}$ s^{-1} **(1)**

(iii) $E_k\left(=\dfrac{hc}{\lambda} - \phi\right)$ =(5.2(3)–3.2) **(1)** $\times 10^{-19} = 2.0 \times 10^{-19}$ J **(1)** 5

[8]

25. (i) speed of electron = $\frac{2.00 \times 3.00 \times 10^8}{100}$ **(1)** (=6.00 × 10^6 (m s^{-1}))

(use of $\lambda = \frac{h}{mv}$ gives) $\lambda = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 6.00 \times 10^6}$ **(1)**

= 1.21 × 10^{-10} m **(1)**

(ii) (use of $c = f\lambda$ gives) $f = \frac{3.00 \times 10^8}{1.21 \times 10^{-10}}$ **(1)**

(allow C.E. for value of λ from (i))

= 2.48 × 10^{18} Hz **(1)** 5

[5]

26. (a) ϕ is <u>minimum</u> energy needed to remove electron **(1)**

E_k is <u>maximum</u> energy of emitted electron **(1)** 2

(b) (i) $E_k = hf - \phi$

$f = \frac{c}{\lambda}$ $\therefore$ $E_k = hc\left(\frac{1}{\lambda}\right) - \phi$ **(1)**

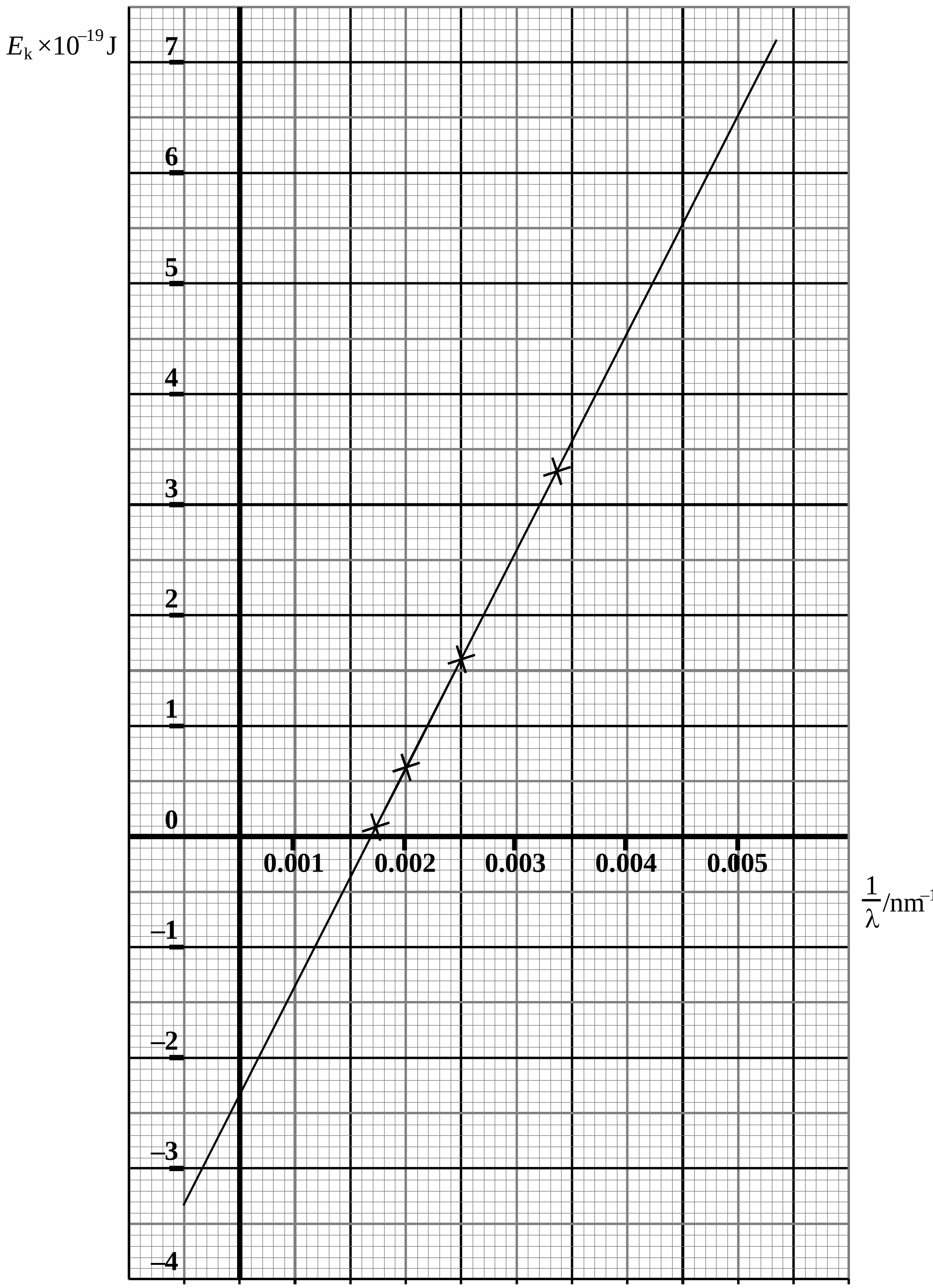
cf $y = mx + c$ **(1)**

(ii)

λ / nm	200	300	400	500	600
$E_k \times 10^{-19}$ J	6.72	3.30	1.68	0.66	0.05
$\frac{1}{\lambda}$ / nm^{-1}	0.0050	0.0033	0.0025	0.0020	0.0017

$\frac{1}{\lambda}$ values correct **(1)**
both axes correctly labelled **(1)**
five points correctly plotted **(1)**
sensible scale and straight line **(1)**

graph for question 5



from intercept, $\phi = 3.3 \times 10^{-19}$ J **(1)** = 2.1 e V **(1)** use of large triangle gives gradient $\left(=\frac{6.7\times10^{-19}}{(5.00-1.65)\times10^{6}}\right)$ = 2.01 × 10^{-25}

$h = \frac{\text{gradient}}{c}$ = 6.7 × 10^{-34} J s **(1)**

max 9

(c) straight line to right of present curve **(1)**
parallel to it **(1)** 2

(d) ultraviolet high frequency **(1)**
above f_0 for emission **(1)**
[or red light low frequency **(1)**
below f_0 for emission **(1)**]

[*alternative (d)*
ultraviolet [red light] photon energy is high [low] **(1)**
above [below] work function **(1)**] 2

[15]

27. (a) $\upsilon \left(= \sqrt{\frac{2E}{m}} \right) = \sqrt{\frac{2 \times 2.0 \times 10^{-18}}{9.1 \times 10^{-31}}}$ **(1)**
$= 2.1 \times 10^6$ m s^{-1} **(1)** 2

(b) (i) difference between E_2 and $E_0 = 1.94 \times 10^{-18}$ J **(1)**
which is less than the electron kinetic energy **(1)**

(ii) $(E_2 - E_1) = 3.06 \times 10^{-19}$ **(1)** $\left(= \frac{hc}{\lambda}\right)$
$\lambda = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{3.06 \times 10^{-19}}$ **(1)** $= 6.5 \times 10^{-7}$ m **(1)**
in visible [or red] region **(1)** 6

(c) for ionisation, p.d. = $\frac{21.8 \times 10^{-19}}{1.6 \times 10^{-19}}$ **(1)** =13.6 V **(1)** 2

[10]

28. (a) an electron is excited/promoted to a higher level/orbit **(1)**
reason for excitation: e.g. electron impact/light/energy externally applied **(1)**
electron relaxes/de-excited/falls back emitting a photon/ em radiation **(1)**
wavelength depends on the energy change **(1)**

Max 3

QWC 1

(b) (i) use of $E = hf$ gives) $E = \frac{hc}{\lambda}$ **(1)**

$= \frac{6.6 \times 10^{-34} \times 3.0 \times 10^{8}}{4.0 \times 10^{-7}}$ $= 5.0 \times 10^{-19}$ (J) **(1)**

(4.95×10^{-19} (J))

and $\left(\frac{6.6 \times 10^{-34} \times 3.0 \times 10^{8}}{2.0 \times 10^{-7}}\right)$ $= 9.9 \times 10^{-19}$ (J) **(1)**

(ii) (energy of) level B = -1.5×10^{-18} (J) **(1)**

level C = (–) 1.0×10^{-18} (J) **(1)** 5

[8]

29. (a) A = down quark; B = W^+ boson; C = positron; D = (electron) neutrino [or v.v. for CD]
(1) (1) [one mark for three correct **(1)**]

(b) W^+ or W^- or Z^0 **(1)**

(c) photon has zero rest mass; W-boson has non-zero rest mass
[or photon has infinite range; W-boson has finite range
or other ref to lifetime] **(1)**

[7]

30. (a) $\upsilon = \frac{h}{m\lambda}$ **(1)** $\left(= \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 1.5 \times 10^{-10}}\right)$ $= 4.86 \times 10^{6}$ ms^{-1} **(1)** 2

(b) yes **(1)**
same order as λ **(1)** 2

[4]

31. (a) inelastic collisions between electrons and atoms **(1)**
energy of atom increases **(1)**
atom emits photon, returns to original state **(1)** 3

(b) photon energy related to wavelength **(1)**
discrete wavelengths suggest fixed energy states of atom **(1)** 2
[5]

32. (a) (i) electrons behave sometimes as particles **(1)**
and sometimes as waves **(1)**

(ii) $m\upsilon \propto 1/\lambda$ (or $m\upsilon = h/\lambda$) **(1)** 3

(b) For (crystal) diffraction, electron wavelength must be of order of atom spacing **(1)**
hence $\lambda \approx 10^{-10}$ m **(1)**

$\upsilon = \frac{h}{m\lambda}$ **(1)** $= \frac{6.6\times10^{-34}}{9.1\times10^{-31}\times10^{-10}} = 7.2(5)\times10^{6}$ m s^{-1} **(1)** 4

(c) deflection in E-field
(or deflection in B-field, or any other correct evidence) **(1)** 1
[8]

33. (a) (i) electronvolt is the energy gained **(1)**
by an electron moved through a p.d of 1 V **(1)**

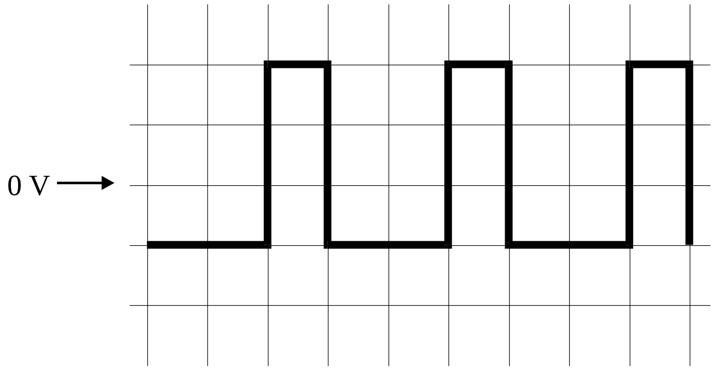
(ii) $\frac{1}{2}m\upsilon^2 = eV$ **(1)**

$\upsilon^2 = \frac{2\times1.6\times10^{-19}\times6000}{9.1\times10^{-31}}$ **(1)** $\upsilon = 4.6\times10^{7}$ ms^{-1} 4

(b) electrons can behave like waves and like particles **(1)** 1
[5]

Electricity

1. The diagram shows a trace on the screen of an oscilloscope. The Y-sensitivity of the oscilloscope is set at 5.0 V per division and the time base is set at 0.50 ms per division.



(a) For the trace, determine

(i) the maximum positive value of potential difference,

....

(ii) the maximum negative value of potential difference,

....

(iii) the frequency of the signal.

....

(4)

(b) The trace shows the variation in the potential difference across a 100 Ω resistor. Calculate the energy dissipated in the resistor

(i) for the first 1.00 ms,

....

....

(ii) between 1.00 ms and 1.50 ms,

....

....

(iii) in one cycle,

....

(iv) in one second.

....

(5)
(Total 9 marks)

2. A very high resistance voltmeter reads 20V when connected across the terminals of a d.c. power supply. The high resistance meter is disconnected and a second voltmeter of resistance 1.0 k Ω is then connected across the supply. The second meter gives a reading of 16 V.

(i) State the e.m.f. of the power supply.

....

(ii) Calculate the current which flows through the second meter.

....

....

(iii) Calculate the internal resistance of the power supply.

....

....

(iv) Show that the current is equal to 0.080 A when the supply is short circuited.

....

....

....

(Total 5 marks)

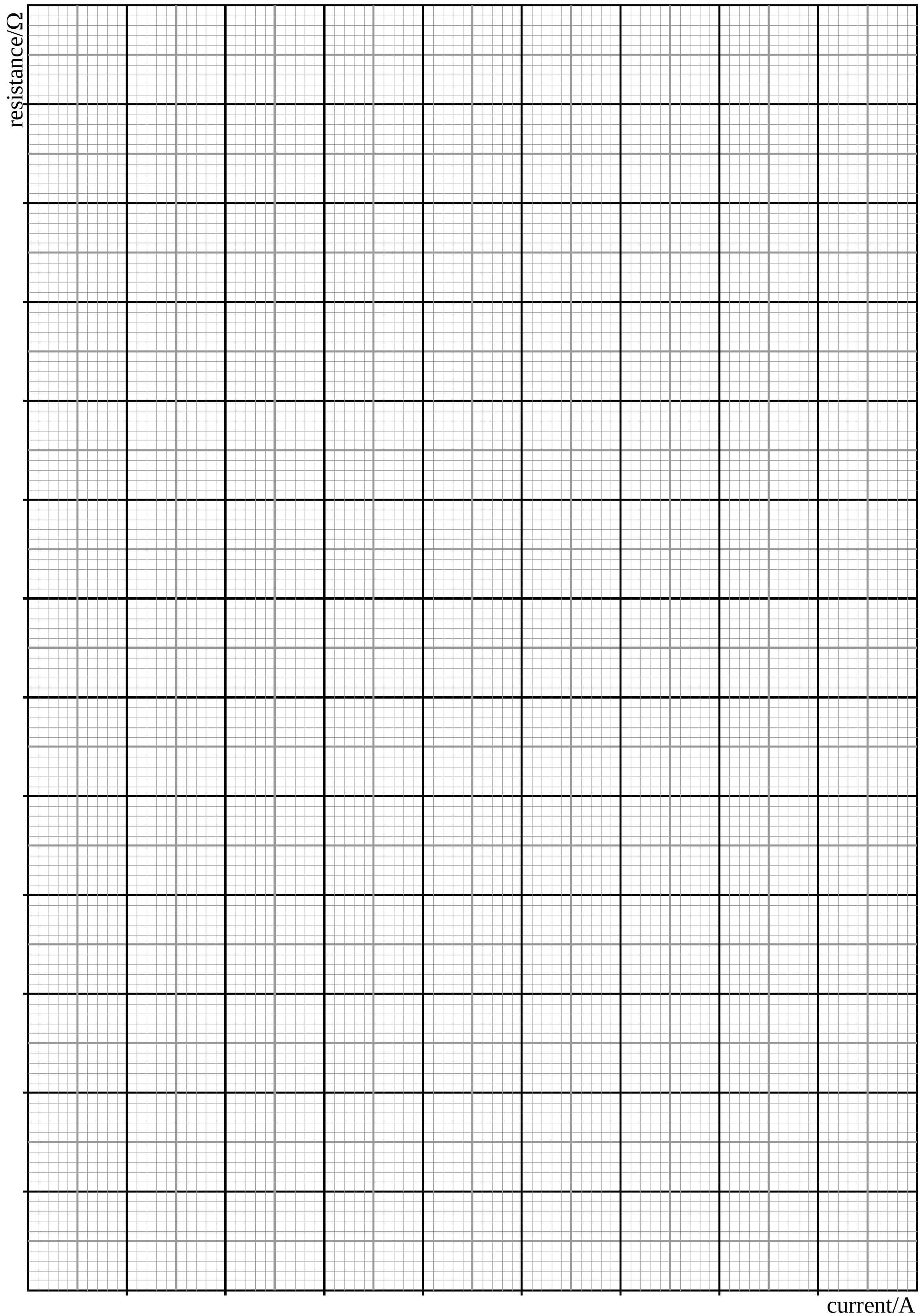
3. In an attempt to investigate how the resistance of a filament lamp varies with current through the lamp, a student obtains the results shown in the table.

voltage /V	0.50	1.50	3.00	4.50	6.00	12.00
current /A	0.51	1.25	2.00	2.55	2.95	4.00
resistance /Ω						

(a) Complete the table by calculating the corresponding values of resistance.

(2)

(b) (i) On the grid below plot a graph of resistance against current for the filament lamp.


resistance/Ω
current/A

(ii) Use your graph to estimate the resistance of the filament lamp when no current flows through the lamp.

....

(iii) Use your graph to determine the change in the resistance of the filament when the current increases

from 0 to 1.0 A, ...

....

from 1.0 A to 2.0 A ....

....

(iv) Calculate the power dissipated in the lamp filament when the current through the filament is 1.0 A and 2.0 A.

1.0 A ....

....

2.0 A ....

....

(8)

(c) Using information from part (b)(iv), explain why the change in resistance of the filament is less for a current change of 0 to 1.0 A than for a current change of 1.0 A to 2.0 A. Do **not** attempt any calculation.

....

....

....

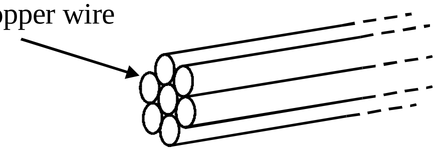
(2)
(Total 12 marks)

4. (a) Show that the unit of resistivity is Ω m.

....

.... **(1)**

(b) A cable consists of seven straight strands of copper wire each of diameter 1.35 mm as shown in the diagram.



Calculate

(i) the cross-sectional area of **one strand** of copper wire,

....

....

(ii) the resistance of a 100 m length of the **cable**, given that the resistivity of copper is 1.6×10^{-8} Ωm.

....

....

.... **(4)**

(c) (i) If the cable in part (b) carries a current of 20 A, what is the potential difference between the ends of the cable?

....

....

(ii) If a single strand of the copper wire in part (b) carried a current of 20 A, what would be the potential difference between its ends?

....

....

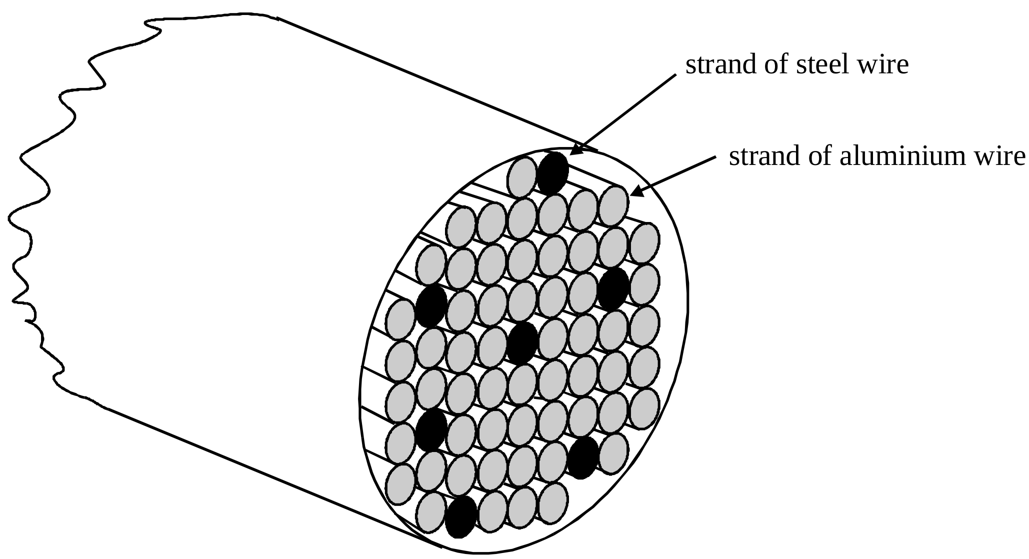
(2)

(d) State **one** advantage of using a stranded rather than a solid core cable with copper of the same total cross-sectional area.

....

(1)
(Total 8 marks)

5. The cable shown in the diagram is used to transmit electricity and is made from strands of steel wire and strands of aluminium wire. The strands of wire are in electrical contact with each other along the length of the cable.



(a) Calculate the resistance of one strand of aluminium wire with a diameter of 3.2 mm and a length of 1.0km.

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(b) The resistance of one strand of steel wire in a 1.0 km length of cable is 19.9 Ω. Calculate the resistance of 1.0 km of the cable made up of seven strands of steel wire and fifty four strands of aluminium wire.

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(Total 5 marks)

6. A particular heating element consists of a 3.0 m length of a metal alloy wire of diameter 1.2 mm and resistivity 9.3×10^{-6} Ωm at the element's operating temperature. The element is designed for use with a 230 V supply. Calculate the rating, in W, of the heating element when in use.

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(Total 4 marks)

7. Two resistors, A and B, have different resistances but otherwise have identical physical properties. E is a cell of negligible internal resistance.

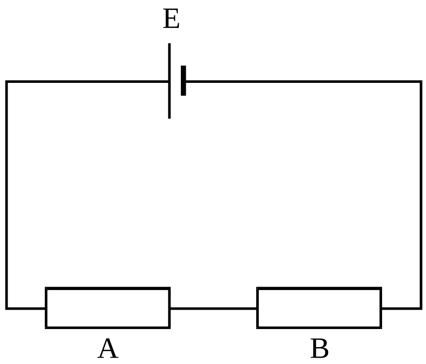

figure 1

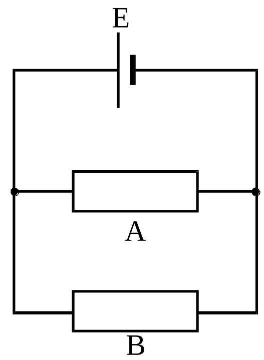

figure 2

When the resistors are connected in the circuit shown in figure 1, A reaches a higher temperature than B. When connected in the circuit shown in figure 2, B reaches a higher temperature than A.

Explain these observations fully, stating which resistance is greater.

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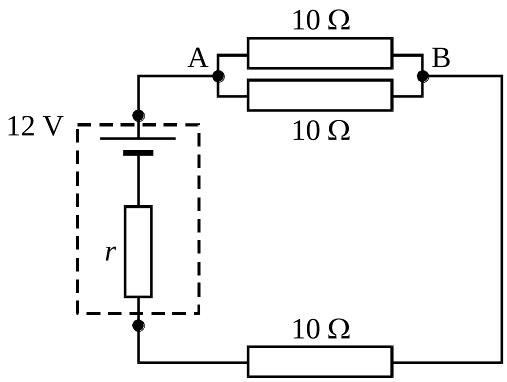
(Total 6 marks)

8. A battery of e.m.f. 12 V and internal resistance *r* is connected in a circuit with three resistors each having a resistance of 10 Ω as shown. A current of 0.50 A flows through the battery.



Calculate

(i) the potential difference between the points A and B in the circuit,

....

....

....

(ii) the internal resistance of the battery,

....

....

....

....

(iii) the total energy supplied by the battery in 2.0 s,

....

....

(iv) the fraction of the energy supplied by the battery that is dissipated within the battery.

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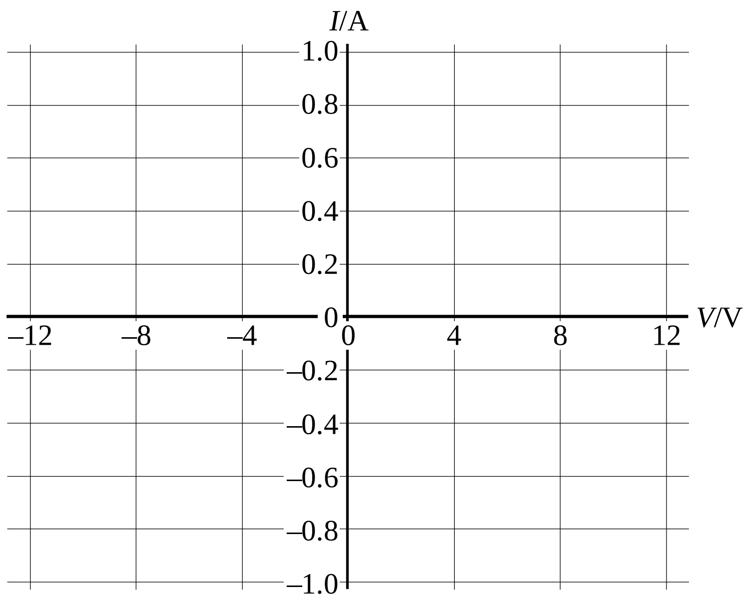
(Total 7 marks)

9. A filament lamp rated 12 V, 1.0 A has a resistance of 4.0 Ω when it carries no current.

(a) On the axes below, sketch the form of the current against voltage characteristic for this lamp.



(4)

(b) The filament lamp is one example of a *non-ohmic* device.

(i) State what is meant by the term *non-ohmic.*

....

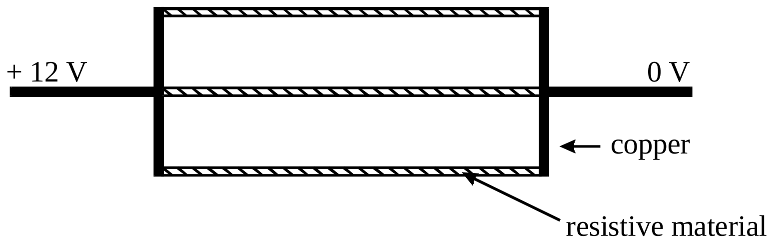
....

(ii) Name **one** other example of a *non-ohmic* device.

....

(2)
(Total 6 marks)

10. A heating element, as used on the rear window of a car, consists of three strips of a resistive material, joined, as shown in the diagram, by strips of copper of negligible resistance. The voltage applied to the unit is 12 V and heat is generated at a rate of 40 W.



(a) (i) Calculate the total resistance of the element.

....

....

(ii) Hence show that the resistance of a single strip is about 11 Ω.

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....

(5)

(b) If each strip is 2.6 mm wide and 1.1 mm thick, determine the length of each strip.

resistivity of the resistive material = 4.0×10^{-5} Ω m

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....

....

(3)

(Total 8 marks)

11. (a) The resistivity of a material in the form of a uniform resistance wire is to be measured. The area of cross-section of the wire is known.

The apparatus available includes a battery, a switch, a variable resistor, an ammeter and a voltmeter.

(i) Draw a circuit diagram using some or all of this apparatus, which would enable you to determine the resistivity of the material.

(ii) Describe how you would make the necessary measurements, ensuring that you have a range of values.

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(iii) Show how a value of the resistivity is determined from your measurements.

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(9)

(b) A sheet of carbon-reinforced plastic measuring 80 mm × 80 mm × 1.5 mm has its two large surfaces coated with highly conducting metal film. When a potential difference of 240V is applied between the metal films, there is a current of 2.0 mA in the plastic. Calculate the resistivity of the plastic.

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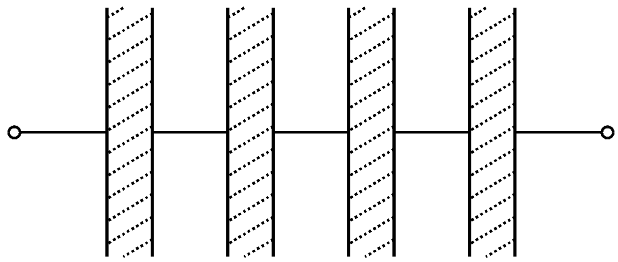
(3)

(c) If four of the units described in part (b) are connected as shown in the diagram, calculate the total resistance of the combination.



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(2)
(Total 14 marks)

12. In each of the following circuits the battery has negligible internal resistance and the bulbs are identical.

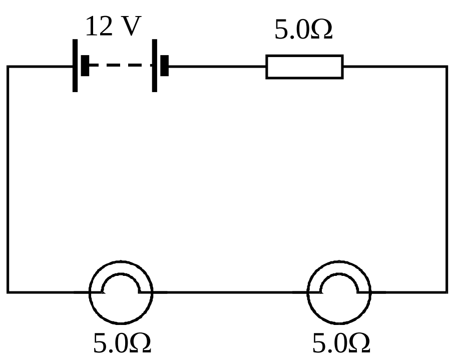

figure 1

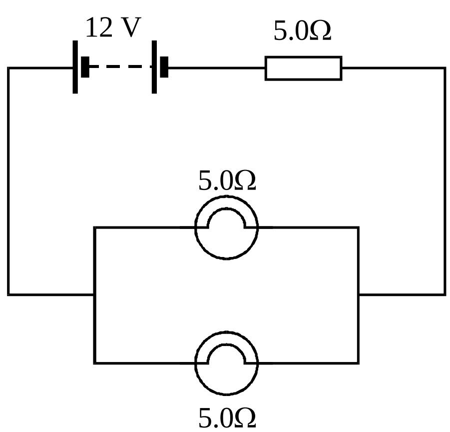

figure 2

(a) For the circuit shown in figure 1 calculate

(i) the current flowing through each bulb,

....

....

(ii) the power dissipated in each bulb.

....

....

(2)

(b) In the circuit shown in figure 2 calculate the current flowing through each bulb.

....

....

....

(3)

(c) Explain how the brightness of the bulbs in figure 1 compares with the brightness of the bulbs in figure 2.

....

....

(2)
(Total 7 marks)

13. (a) A metal wire of length 1.4 m has a uniform cross-sectional area = 7.8×10^{-7} m^2.
Calculate the resistance, *R*, of the wire.
resistivity of the metal = 1.7×10^{-8} Ωm

....

....

....

....

(2)

(b) The wire is now stretched to twice its original length by a process that keeps its volume constant. If the resistivity of the metal of the wire remains constant, show that the resistance increases to 4*R*.

....

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....

....

(2)

(Total 4 marks)

14. (a) A pencil "lead" is made from non-metallic material which has a resistivity, at room temperature, of 4.0×10^{-3} Ωm. A piece of this material has a length of 20mm and a diameter of 1.40 mm.

Show that the resistance of this specimen, to two significant figures, is 52 Ω.

....

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....

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(2)

(b) Given a specimen of the pencil "lead" described in part (a) with similar dimensions, describe an experiment you could carry out in the school or college laboratory to verify that the resistivity of the material is equal to the value quoted in part (a).

Your description should include

- a labelled circuit diagram,
- details of the measurements you would make,
- an account of how you would use your measurements to determine the result.

(Allow one lined page)

(8)

(c) During an experiment such as that described in part (b), a specimen of pencil "lead" is found to have a resistance of 52 Ω when the current through it is 250 mA.

Calculate the power dissipated in the specimen under these conditions.

....

....

....

(2)
(Total 12 marks)

15. (a) Some electrical components may be described as *non-ohmic*.

(i) Name an example, other than a diode, of a non-ohmic electrical component.

....

(ii) State how the current-voltage characteristic of your chosen component shows that it is non-ohmic.

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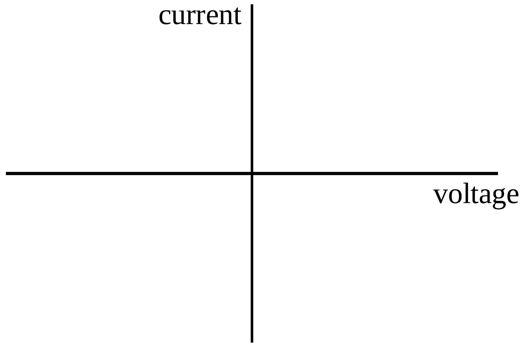
....

....

(2)

(b) A semiconducting diode has special electrical properties that make it useful as an electrical component.

(i) Sketch on the grid the current-voltage characteristic of a diode.



(ii) State, with reference to the current-voltage characteristic you have drawn, how the resistance of the diode varies with the potential difference across its terminals for reverse bias and for forward bias.

reverse biased: ....

....

forward biased: ....

....

(4)
(Total 6 marks)

16.

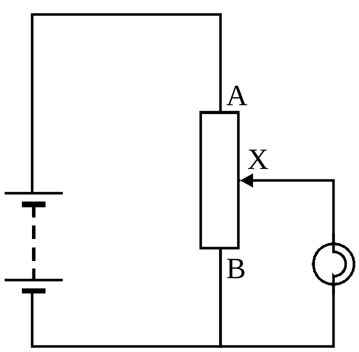


figure 1

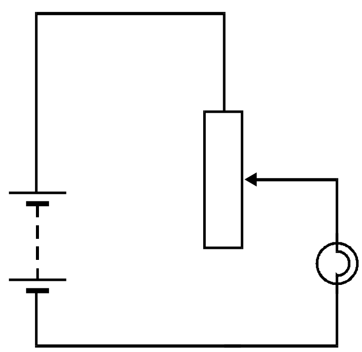


figure 2

(a) The current flowing through a torch bulb can be controlled by a variable resistor using either of the two circuit arrangements shown above. Figure 1 is called a potential divider arrangement and figure 2 may be called a rheostat arrangement. For each of these two methods explain **one** advantage and **one** disadvantage.

potential divider

advantage ....

....

disadvantage ....

....

rheostat

advantage ....

....

disadvantage ....

....

(4)

(b) In figure 1, the variable resistor has a total resistance of 16 Ω. When the slider of the variable resistor is set at X, exactly mid-way along AB, the bulb works according to its specification of 2.0 V, 500 mW. Calculate

(i) the current through section XB of the variable resistance,

....

....

(ii) the current through section AX of the variable resistance.

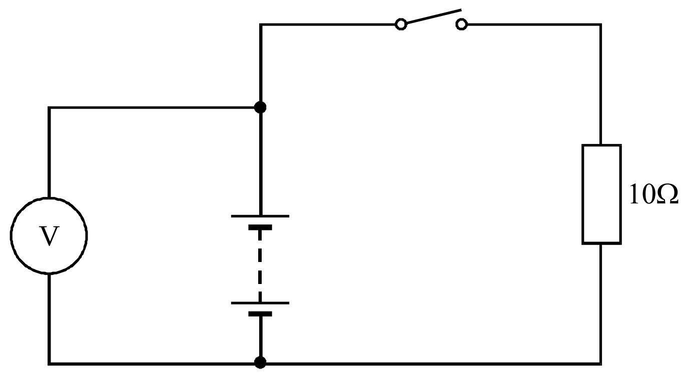
....

....

(2)

(Total 6 marks)

17.



A battery is connected to a 10Ω resistor as shown. The e.m.f. (electromotive force) of the battery is 12V.

(a) (i) Explain what is meant by the e.m.f. of a battery.

....

....

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....

(ii) When the switch is open the voltmeter reads 12.0V and when it is closed it reads 11.5 V. Explain why the readings are different.

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....

....

(3)

(b) Calculate the internal resistance of the battery.

....

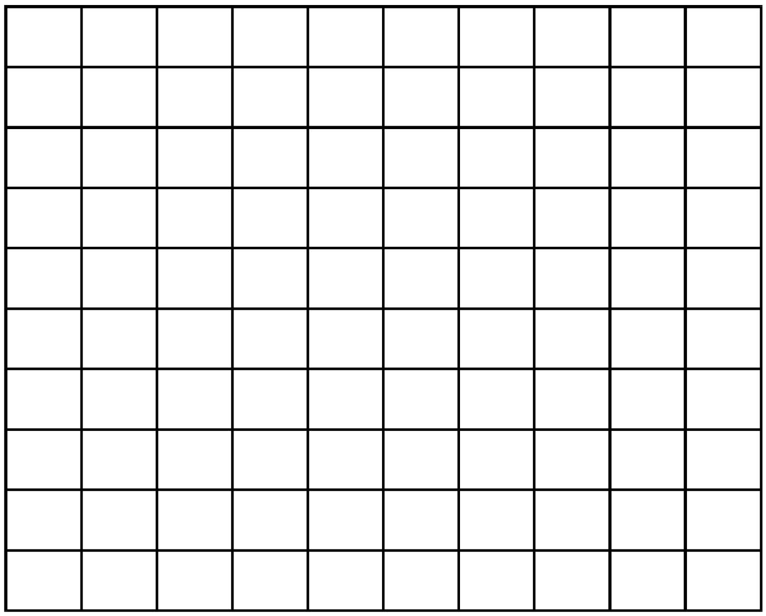
....

....

(3)

(Total 6 mark)

18. A cathode ray oscilloscope is used to study the waveform of a sinusoidal alternating voltage of frequency 100 Hz and peak voltage 2.0 V. If the time base is set to 2.0 ms div^{-1} and the voltage sensitivity is 0.5 V div^{-1}, draw, in the grid below, the trace you would expect to see on the screen.



(Total 4 marks)

19. (a) In the circuit shown in **Figure 1**, the battery has an emf of 12 V and negligible internal resistance.

PQ is a potential divider, S being the position of the sliding contact. In the position shown, the resistance between P and S is 180 Ω and the resistance between S and Q is 60 Ω.

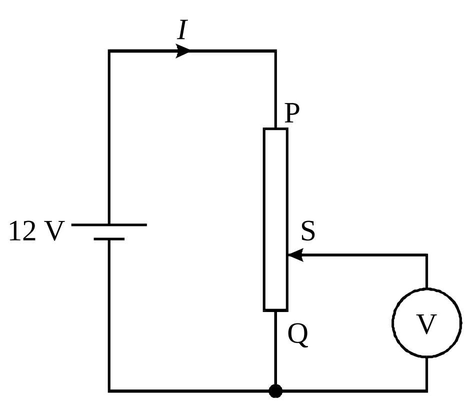


Figure 1

(i) Calculate the current, *I*, in the circuit, assuming that there is no current through the voltmeter V.

....

....

....

(ii) What property of the voltmeter allows us to assume that no current flows through it?

....

....

(iii) What is the reading on the voltmeter?

....

....

(4)

(b) The circuit in **Figure 1** is modified as shown in **Figure 2**, by exchanging the voltmeter for a load R, whose resistance is about the same as the resistance of section SQ of the potential divider.

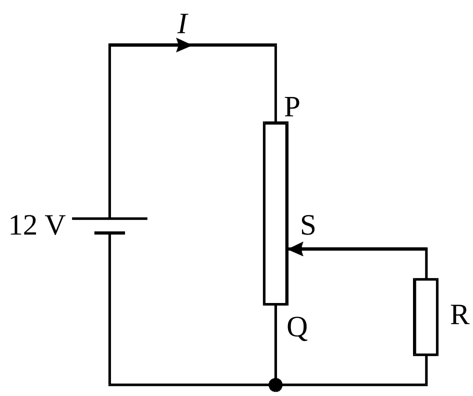


Figure 2

Explain, without calculation, why the current through the battery increases in value from that in part (a).

You may be awarded marks for the quality of written communication in your answer.

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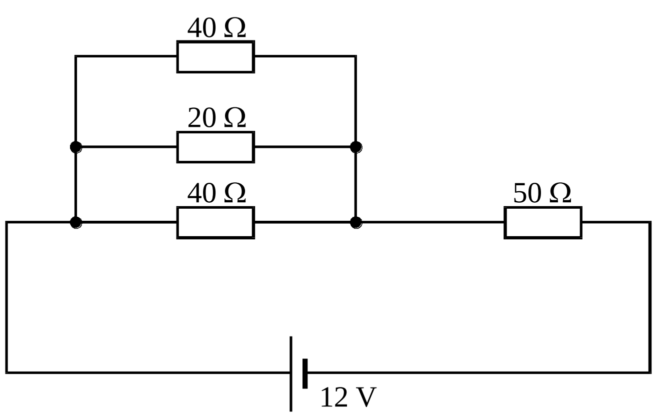
(2)
(Total 6 marks)

20. A battery of e.m.f 12 V and negligible internal resistance is connected to a resistor network as shown in the circuit diagram.



(a) Calculate the total resistance of the circuit.

....

....

....

....

....

(3)

(b) Calculate the current through the 50 Ω resistor.

....

....

(1)
(Total 4 marks)

21. Columns **A and B** show some of the results from an experiment in which the current *I* through a component X was measured for various values of the potential difference *V* applied across it.

column A	**column B**	**column C**	**column D**
potential difference *V* / V	current *I*/ mA	(*V* – 0.55) / V	In (*I* / mA)
0.70	12.5		
0.75	17.0		
0.80	22.0		
0.85	29.0		
0.90	39.0		
0.95	51.5		

(a) Draw a diagram of a circuit which could have been used to obtain these results.

(2)

(b) (i) Calculate the resistance of X when the potential difference is 0.70 V.

....

....

(ii) By considering **one** other value of potential difference, explain whether or not X is an ohmic conductor.

....

....

....

....

(3)

(c) It is suggested that for potential differences greater than 0.55 V, the current voltage relationship for X is of the form.

$$I = A\,\mathrm{e}^{k(V-0.55)}$$

where A and k are constants.

(i) Complete **column C** and **column D** in the abive

(ii) Plot a graph of 1n (I /mA) on the y-axis against (V – 0.55) on the x-axis.

(Allow one sheet of graph paper)

(iii) Use your graph to determine the constants k and A.

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(iv) On the basis of your graph, discuss the validity of the above relationship.

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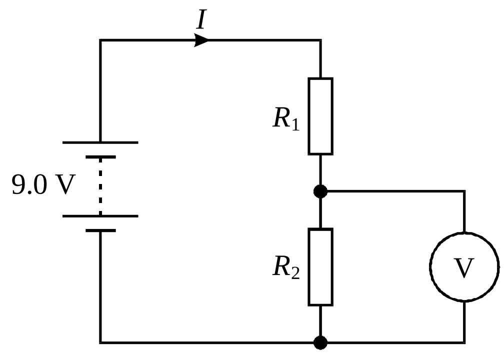
(10)
(Total 15 marks)

22. In the circuit shown, the battery has negligible internal resistance.



(a) (i) If the emf of the battery = 9.0 V, R_1 = 120 Ω and R_2 = 60 Ω**,** calculate the current I flowing in the circuit.

....

....

....

....

(ii) Calculate the voltage reading on the voltmeter.

....

....

(4)

(b) The circuit shown in the diagram acts as a potential divider. The circuit is now modified by replacing R_1 with a temperature sensor, whose resistance decreases as the temperature increases.

Explain whether the reading on the voltmeter increases or decreases as the temperature increases from a low value.

....

....

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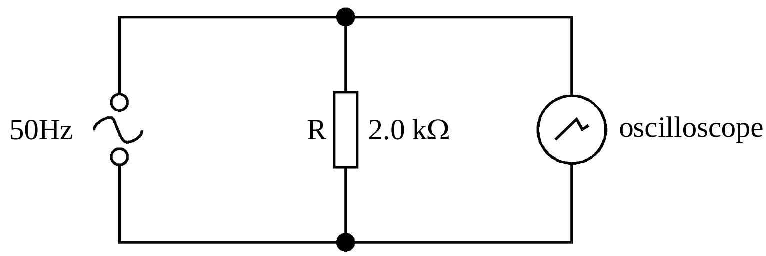
....

....

(3)
(Total 7 marks)

23. A sinusoidal alternating current (ac) source of frequency 50 Hz, is connected to a resistor of resistance 2.0 kΩ and an oscilloscope, as shown. The rms current through the resistor is 5.0 mA.



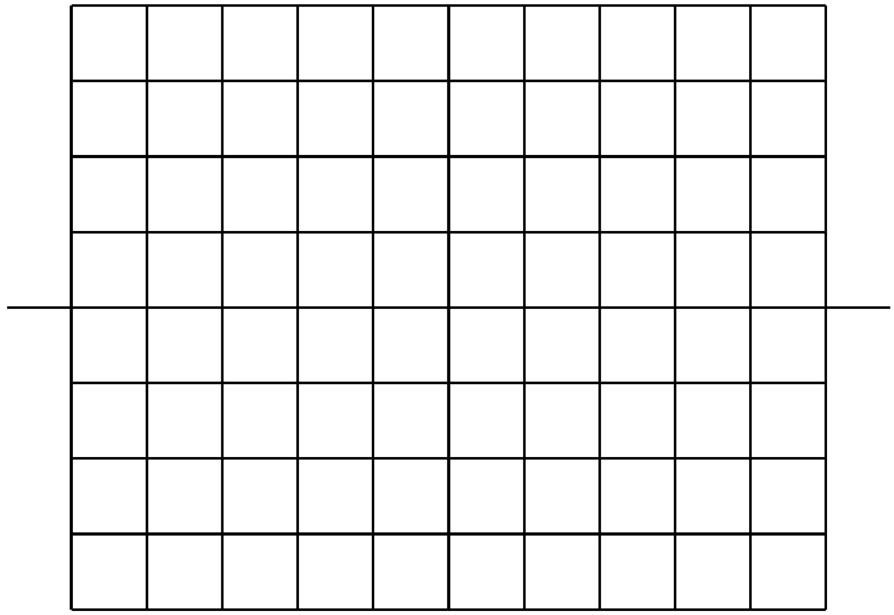
(a) Calculate the peak value of the voltage across R.

....

....

(2)

(b) The grid represents the screen of the oscilloscope, each square being 1 cm × 1 cm. The time base of the oscilloscope is set at 5 ms cm^{-1} and the voltage sensitivity is 4.0 V cm^{-1}.



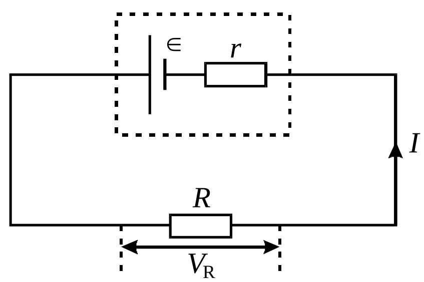
(i) Calculate the period of the ac signal.

....

(ii) Draw, on the grid, the signal you would expect to see on the oscilloscope.

(4)
(Total 6 marks)

24. (a) A cell of emf ∈ and internal resistance r is connected in series to a resistor of resistance R as shown. A current I flows in the circuit.



(i) State an expression which gives ∈ in terms of I, r and R.

....

(ii) Hence show how V_R, the potential difference across the resistor, is related to ∈, I and r.

....

(2)

(b) A lamp, rated at 30 W, is connected to a 120 V supply.

(i) Calculate the current in the lamp.

....

....

(ii) If the resistor in part (a) is replaced by the lamp described in part (b), determine how many cells, each of emf 1.5 V and internal resistance 1.2 Ω, would have to be connected in series so that the lamp would operate at its proper power.

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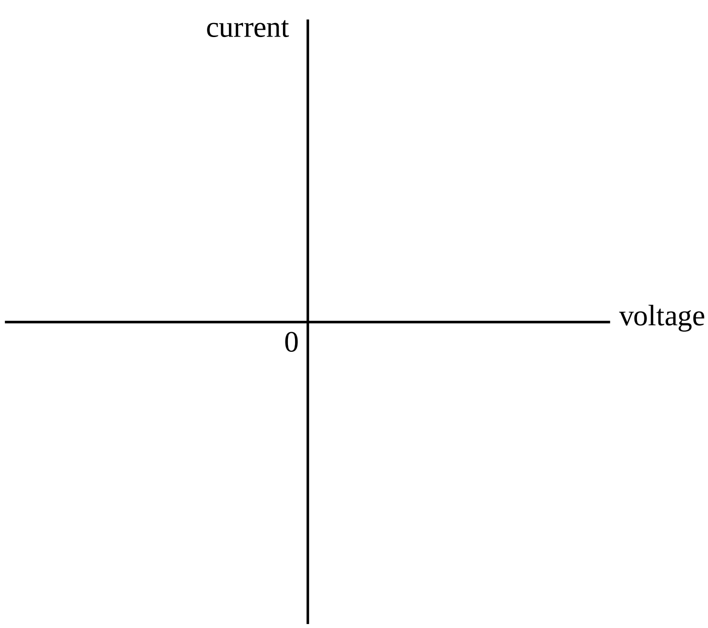
(5)
(Total 7 marks)

25. (a) Draw, on the axes below, the current/voltage characteristic for a filament lamp. Do **not** insert any values for current or voltage.



(3)

(b) Explain why the characteristic has the shape you have drawn.

....

....

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....

....

(3)

(c) The current/voltage characteristic of a filament lamp is to be determined using a datalogger, the data then being fed into a computer to give a visual display of the characteristic. Draw the circuit diagram required for such an experiment and state what is varied so as to produce a range of values.

....

....

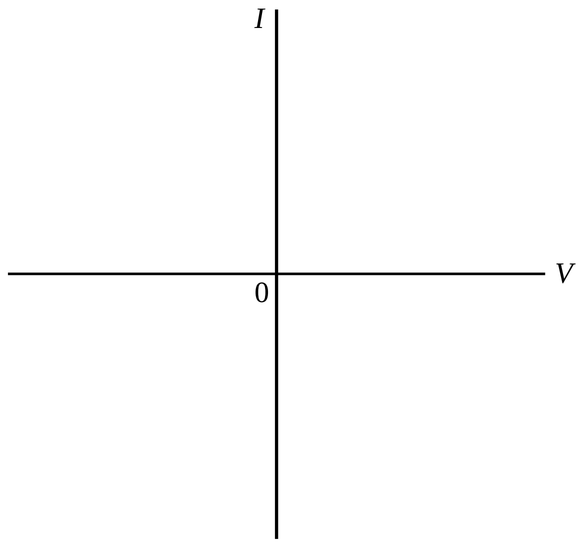
....

....

(5)
(Total 11 marks)

26. (a) Using the axes below, sketch the characteristic of a silicon semiconductor diode for forward bias and reverse bias.

Indicate approximate values on the voltage axis.



(4)

(b) Describe, with reference to the characteristic you have drawn, how the resistance of the diode changes with the voltage across the diode.

....

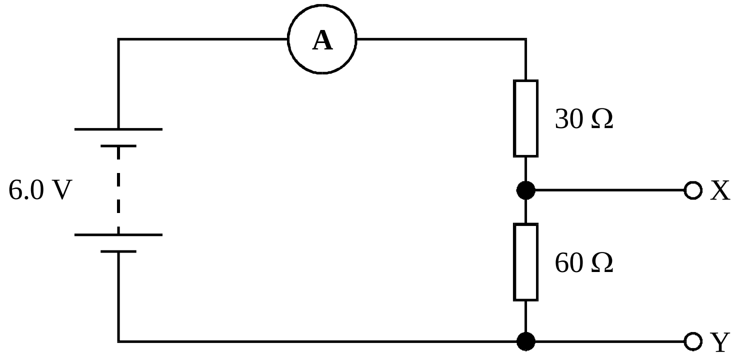
....

....

....

(3)
(Total 7 marks)

27. In the circuit shown, the battery has negligible internal resistance.



Calculate the current in the ammeter when

(a) the terminals X and Y are short-circuited i.e. connected together,

....

....

....

....

(2)

(b) the terminals X and Y are connected to a 30 Ω resistor.

....

....

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(4)

(Total 6 marks)

28. A battery of e.m.f. $\in$ and internal resistance r is connected in series with a variable resistor R as shown in **Figure 1**. A voltmeter is connected as shown.

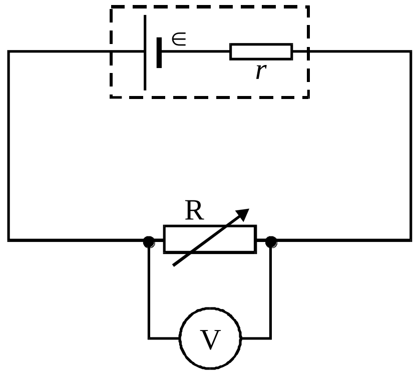


Figure 1

(a) (i) State what is meant by the e.m.f of a battery.

....

....

(ii) The reading V on the voltmeter is the voltage across R.
Why is V less than $\in$?

....

....

(3)

(b) In order to measure $\in$ and r, an ammeter is used in the circuit, as shown in **Figure 2.**

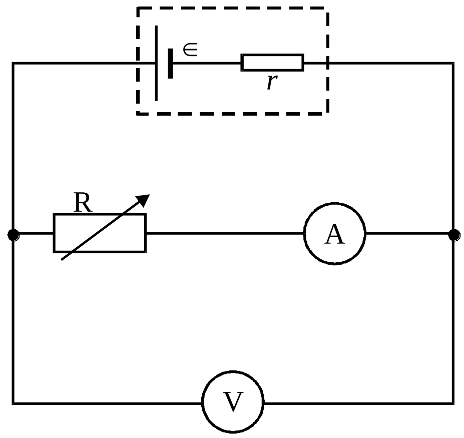
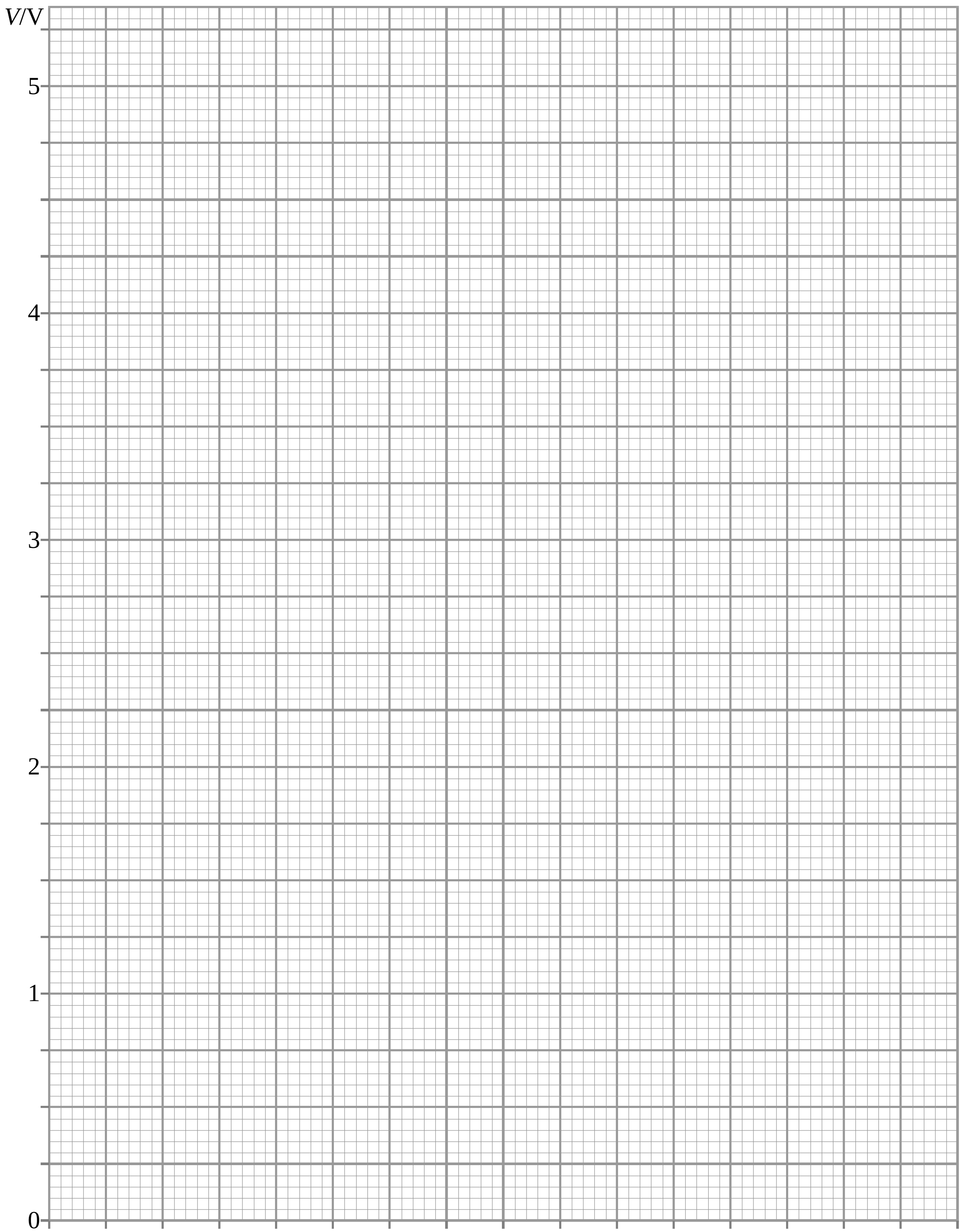


Figure 2

The value of R is decreased in steps and at each step the readings V and I on the voltmeter and ammeter, respectively, are recorded. These are shown in the table.

reading on voltmeter/V	reading on ammeter/A
4.0	0.07
3.0	0.14
2.0	0.21
1.0	0.28

(i) Plot a graph of V (on y axis) against I (on x axis) and draw the best straight line through the points.



(ii) Determine the values of ∈ and r from the graph, explaining your method.

....

....

....

....

....

....

(8)

(Total 11 marks)

Answers

1. (a) (i) 10(V) **(1)**

(ii) 5.0(V) **(1)**

(iii) T = 150 V (ms) **(1)** $f = \frac{1}{T}$ = 667 Hz **(1)** 4

(b) (i) I = $\frac{V}{R}$ = 0.050(A) **(1)** [or substitute in $P = \frac{V^2}{R}$ **(1)**]

$E_1 = VIt = 25 \times 10^{-4}$ J **(1)**

(ii) I = 0.10(A) **(1)** $E_2 = 5.0\times10^{-4}$ J **(1)** [or substitute in $P = \frac{V^2}{R}$ **(1)**]

(iii) $E_t = 7.5 \times 10^{-4}$ J **(1)**

(iv) P = 667 **(1)** × 7.5 × 10^{-4} = 0.50Js^{-1} **(1)** (accept J)

max 5

[9]

2. (i) 20V **(1)**

(ii) 1.6×10^{-2} A **(1)**

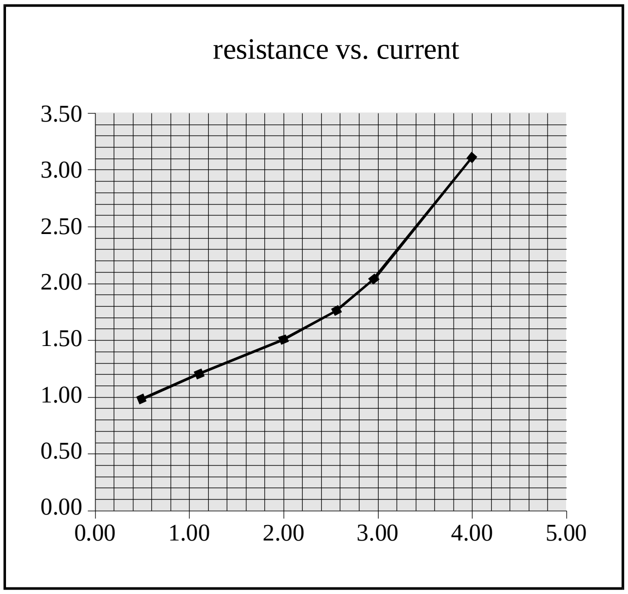
(iii) $r = \frac{4.0}{(1.6\times10^{-2})}$ [or 20 = 0.016(1000 + r) **(1)** =250Ω **(1)**

(iv) $I = \frac{20}{250}$ **(1)** = 8.0×10^{-2} A

[5]

3. (a) (i) resistance/Ω 0.98 1.20 1.50 1.76 2.03 3.00 **(1) (1)**
[deduct one mark for each incorrect value] 2

(b) (i) sensible scales chosen **(1)**
points plotted correctly [deduct one mark for each mistake] **(1) (1)**
line of best fit **(1)**



(ii) 0.90 Ω **(1)**

(iii) 0.22 Ω **(1)**
0.38 Ω **(1)**

(iv) 1.12 W **(1)**
6.0 W **(1)**

max 8

(c) resistance increases with increasing temperature **(1)**
increase in heat dissipation for 1.0 A to 2.0 A is greater than for 0 to 1.0 A **(1)**
and so a greater corresponding rise in temperature **(1)**

max 2

[12]

4. (a) $\rho = \frac{RA}{l} \Rightarrow \frac{\Omega m^2}{m} \Rightarrow \Omega m$ 1

(b) (i) $A = 1.43 \times 10^{-6}$ m^2 **(1)**

(ii) $R_{strand} = \frac{1.6 \times 10^{-8} \times 10^{2}}{1.4 \times 10^{-6}} = 1.1\Omega$ **(1)**

$R_{cable} = \frac{1.12}{7}$ **(1)** $= 0.16\Omega$ **(1)**

alternative (ii):
A = 7 **(1)** × 1.4 × 10^{-6}
substitution **(1)**
leading to $R_{cable} = 0.16\ \Omega$ **(1)** 4

(c) (i) $V = 3.2$ V **(1)**

(ii) $V = 7 \times 3.2$ V = 22V **(1)** 2

(d) cable is flexible (*)
one strand fails, cable continues to conduct (*)
larger surface area so better heat dissipation etc (*)
(*) any one **(1)** 1

[8]

5. (a) $R\left(= \frac{\rho l}{A}\right) = \frac{2.65 \times 10^{-8} \times 1.0 \times 10^{3} \times 4}{\pi \times (3.2 \times 10^{-3})^{2}}$ **(1)**
= 3.3(0) Ω **(1)**

(b) $\frac{1}{R_{Al}} = \frac{54}{3.3}$ **(1)** $\frac{1}{R_{steel}} = \frac{7}{19.9}$
$\left(\frac{1}{R_{tot}} = \frac{1}{R_{Al}} + \frac{1}{R_{steel}}\right) = 0.06(0)\Omega$ **(1)**

[5]

6. $A = 1.13 \times 10^{-6}$ (m^2) **(1)**

$R = \frac{\rho l}{A} = 24.7(\Omega)$ **(1)**

$P = \frac{V^2}{R}$ [or $I = 9.32$ A] **(1)** $= 2.1(4) \times 10^3$ (W) **(1)**

[4]

7. power determines heat produced **(1)**
in series, current is same **(1)**
$\therefore I^2 R_A$ must be $> I^2 R_B$ **(1)**
in parallel, p.d. is same **(1)**
$\therefore \frac{V^2}{R_B}$ must be $> \frac{V^2}{R_A}$ **(1)**
$\therefore R_A > R_B$ **(1)**

[6]

8. (i) $R_{AB} = 5.0(\Omega)$ **(1)**
$V (= 5.0 \times 0.50) = 2.5\text{V}$ **(1)**

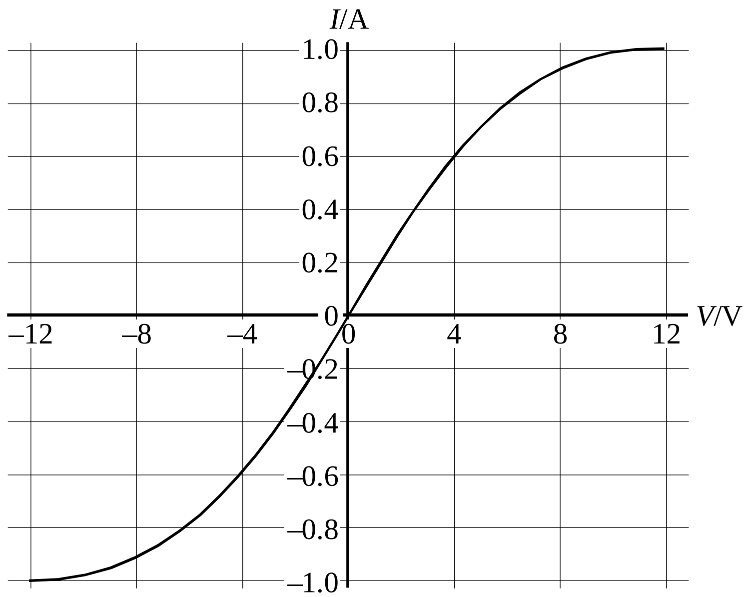
(ii) $V_r = 12 - 2.5 + 5.0$ **(1)** $= 4.5(\text{V})$ **(1)**
$r = \left(\frac{V_r}{I} = \frac{4.5}{0.5}\right)\ 9.0\ \Omega$ **(1)**

(iii) $W(= EIt) = 12\text{J}$ **(1)**

(iv) $W_r(= V_r It) = 4.5(\text{J})$ **(1)**
$\frac{W_r}{W}\ \left(= \frac{4.5}{12}\right) = 0.375$ **(1)**

[Max 7]

9. (a)



shape in one quadrant **(1)**
symmetrical **(1)**
(1.0, 1.2) **(1)**
(0, 0) **(1)**
slope at (0, 0) **(1)**

max 4

(b) (i) *V* is not directly proportional to *I* [or resistance is constant] **(1)**

(ii) e.g. semiconductor diode **(1)** 2

[6]

10. (a) (i) $P = \frac{V^2}{R}$ = gives 40 = $\frac{144}{R_T}$ **(1)**

$R_T = 3.6\ \Omega$ **(1)**
[or $P = VI$ to give $I = 3.3$ (A) **(1)** and $R = P/I^2 = 3.7\ \Omega$ ($3.67\ \Omega$) **(1)**]

(ii) three resistors in parallel **(1)**

$$\frac{1}{R_T} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} = \frac{3}{R}$$ **(1)**

$R = 3.6 \times 3 = 10.8$ (Ω) **(1)**

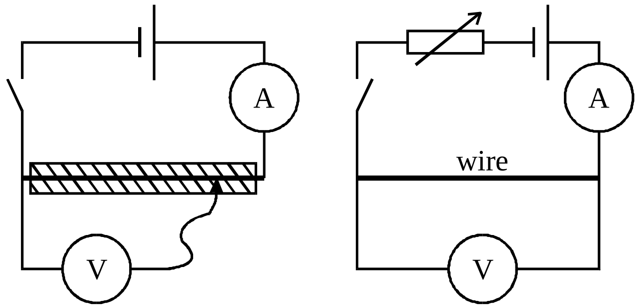
(allow C.E. for R_T from (i)) 5

(b) (use of $R = \frac{\rho l}{A}$ = gives) $10.8 = \frac{4.0\times10^{-5} l}{2.6\times10^{-3}\times1.1\times10^{-3}}$ **(1)**

$l = \frac{10.8\times2.6\times10^{-3}\times1.1\times10^{-3}}{4.0\times10^{-5}}$ **(1)**

= 0.77 m **(1)** (allow C.E for *R* from (a)(ii) 3

11. (a) (i)



(1) battery, wire, (variable resistor) and ammeter in series
(1) voltmeter connected across wire

(ii) (α) (with switch closed) measure I and V **(1)**
move contact along the wire **(1)** (or length of wire changed)
measure new (I and) V **(1)**
measure l each time **(1)**

or (β) measure I and V **(1)**
change variable resistor **(1)**
measure new I and V **(1)**
l known **(1)**

(iii) $R = \frac{\rho l}{A}$ or $\rho = \frac{RA}{l}$ or $\rho = \frac{A}{l} \times \frac{V}{I}$ **(1)**
(α) obtain gradient of graph of V or R vs l **(1)**
A (and I) known, hence ρ **(1)**

or (β) gradient of graph of V vs I **(1)**
A and l known, hence ρ **(1)**
[or, for both methods, measure $R = \frac{V}{I}$ for each length **(1)**
take mean and hence ρ **(1)** 9

(b) (use of $V = IR$ gives) $R = \frac{240}{2 \times 10^{-3}}$ **(1)** ($= 120 \times 10^3$ (Ω))

$$\rho = \left(\frac{RA}{l}\right) = \frac{120\times10^{3}\times80\times80\times10^{-6}}{1.5\times10^{-3}}$$ **(1)**

(allow C.E. for value of *R*)

$= 5.1 \times 10^{5}\ \Omega\ \text{m}$ **(1)** 3

(c) four resistors in series **(1)**
$R = 4 \times (120 \times 10^3) = 4.8 \times 10^5\ \Omega$ **(1)**
(allow C.E. for value of R) 2

[14]

12. (a) (i) $I = \frac{12}{15} = 0.80$ A **(1)**

(ii) P = $(0.80)^2 \times 5 = 3.2$W **(1)** (allow e.c.f. from (a)(i)) 2

(b) $I_{tot} = \frac{12}{7.5}$ **(1)** = 1.60 (A) **(1)**

$I = \frac{1.6}{2}$ = 0.80 (A) **(1)** (allow e.c.f. from I_{tot}) 3

(c) same brightness **(1)**
because same current **(1)**
[or an answer consistent with their current values] 2

[7]

13. (a) $R = \frac{\rho l}{A}$ **(1)**

$= \frac{1.7 \times 10^{-8} \times 1.4}{7.8 \times 10^{-7}} = 0.031\ \Omega$ **(1)** (0.0305 Ω) 2

(b) constant volume gives $l_1 A_1 = l_2 A_2$
[or $l_2 = 2l_1$ and $A_2 = A_1/2$] **(1)**

$R = \frac{\rho 2l}{A/2} = 4R$ **(1)**

[or calculation with l_2 = 2.8 (m) and A_2 = 3.9 (m^2) **(1)**]
gives R = 0.124 Ω **(1)**] 2

[4]

14. (a) $R = \frac{\rho l}{A} = \frac{4.0\times10^{-3}\times20\times10^{-3}}{\pi\times(0.70\times10^{-3})^2}$ **(1) (1)** = (52 Ω) 2

(b) *method 1*

valid labelled circuit **(1)** [sample identified and label override circuit symbols]
with means of changing I or V **(1)** [variable supply may be in text]
measure p.d., current and find resistance **(1)** [$R = V/I$ or graphically]
repeat finding resistance by changing potential divider
(or variable R or variable supply or length of lead) **(1)**

OR

method 2

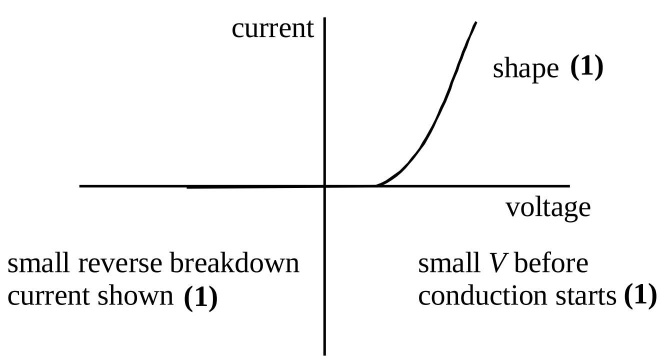
ohmmeter in circuit diagram **(1)**
change conditions (e.g. scale, length of lead) **(1)**
read ohmmeter **(1)**
repeat readings **(1)** 8

(c) $P = I^2R = (0.25)^2 \times 52$ **(1)**
$= 3.25\text{W}$ **(1)** 2
[12]

15. (a) (i) e.g. filament lamp **(1)**

(ii) not a straight line
[or does not pass through origin, only if applied to
example e.g. photodiode] **(1)** 2

(b) (i)



(ii) *reverse*: high resistance [or constant resistance] **(1)**
forward: low resistance **(1)** max 4

[6]

16. (a) *potential divider*:

advantage: better control from 0 to maximum **(1)**

disadvantage: power wasted because lower half of resistor always carries current (or top half of resistor must be capable of carrying lower half current **and** bulb current) **(1)**

rheostat:

advantage: easier to connect **(1)**

disadvantage: minimum current through bulb never zero **(1)** 4

(b) (i) $V_{XB} = V_{lamp} = 2.0V \therefore I_{XB} = \frac{2}{16/2} = 0.25$ A **(1)**

(ii) $I_{AX} = I_{XB} + I_{lamp}$, $I_{lamp} = I_{XB} = 0.25$ A, $\therefore I_{AX} = 0.5$ A **(1)** 2

[6]

17. (a) (i) the energy provided by a battery **(1)** per unit charge **(1)**
[or when no current flows **(1)** it is the potential difference across the battery **(1)**]

(ii) a potential difference is developed across the internal resistance **(1)** 3

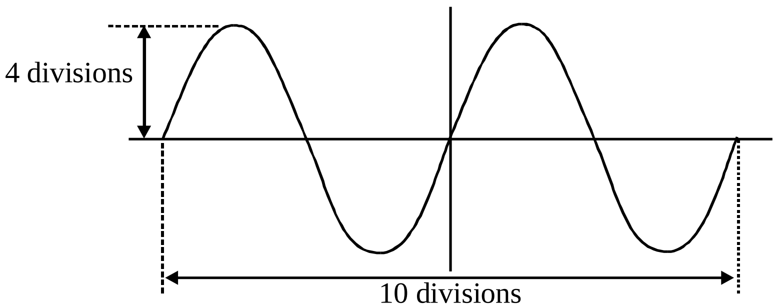
(b) $I = \frac{11.5}{10} = 1.15$(A) **(1)**

$12 - 11.5 = 1.15 \times r$ **(1)**

$r = 0.43\ \Omega$ **(1)** 3

[6]

18.



sinusoidal wave
(line gradient must be changing and distance between crests and troughs symmetric) **(1)**
correct amplitude **(1)**
calculation of time period shown or implied **(1) (1)**
two cycles drawn **(1)** (allow e.c.f. if incorrect time period *calculated*)

[4]

19. (a) (i) total resistance = 180 + 60 = 240 (Ω) **(1)**
($V = IR$ gives) 12 = I 240 and I = 0.05 **A (1)**

(ii) very large or infinite resistance **(1)**

(iii) $V = 0.05 \times 60 = 3.0$V **(1)**
[or statement that $V = \frac{1}{4}$ of 12 V]
[or use of potentiometer equation

$$V_{out} = V_{in}\left[\frac{R_2}{R_1 + R_2}\right] = 12 \times \left[\frac{60}{240}\right] = 3.0 \text{ V}]$$

(allow C.E. for value of I from (a)(i)) 4

(b) parallel resistance gives lower equivalent resistance
[or resistance of lower section of potentiometer reduced] **(1)**
total resistance in circuit reduced **(1)**
current through battery increases since V constant **(1)**

max 2

QWC 2

[6]

20. (a) (three parallel resistors) give $\frac{1}{40}+\frac{1}{20}+\frac{1}{40}=\frac{1}{R}$ **(1)**

R = 10 (Ω)**(1)**
10 Ω and 50 Ω in series gives 60 Ω **(1)**
(allow e.c.f. from value of R) 3

(b) ($V = IR$ gives) 12 = I × 60 and I = 0.2 A **(1)**
(allow e.c.f. from (a)) 1

[4]

21. (a) circuit diagram to show:
ammeter in series, voltmeter in parallel **(1)**
variable source (e.g. battery + rheostat or potential divider) **(1)** 2

(b) (i) $R_X = \frac{0.70}{12.5\times10^{-3}}$ = 56 Ω **(1)**

(ii) R_X = (e.g.) $\frac{0.90}{39\times10^{-3}}$ = 23 (Ω) **(1)**
R_X depends on current (or voltage) $\therefore$ non-ohmic 3

(c) (i)

col C	col D
0.15	2.53
0.20	2.83
0.25	3.09
0.30	3.37
0.35	3.66
0.40	3.94

four pairs of values correct **(1)**
all six pairs correct and col D to no more than 4 s.f **(1)**

(ii) axes labelled **(1)**
suitable scales chosen **(1)**
at least five points plotted correctly **(1)**
acceptable straight line **(1)**

(iii) k = gradient **(1)**
gradient = $\dfrac{3.95 - 1.68}{0.40}$ = 5.7 (V^{-1}) **(1)**
intercept on y-axis =ln A **(1)**
(intercept = 1.68 gives) $A = e^{1.68}$ = 5.4 (mA) **(1)**
unit for k or A correct **(1)**

(iv) the points define a straight line **(1)**
valid over given range **(1)**

max 10

[15]

22. (a) (i) (use of $V = IR$ gives) $V = I(R_1 + R_2)$ **(1)**

$$I = \frac{V}{R_1 + R_2} = \frac{9}{120 + 60}$$ **(1)**
= 50 mA ✓

(ii) V_{out} (= IR_2) = 0.05 × 60 = 3 V **(1)**
(allow C.E. for value of I from (i)) 4

(b) (temperature increases, resistance decreases), total resistance decreases **(1)**
current increases **(1)**
voltage across R_2 increases **(1)**
[or R_2 has increased share of (total) resistance **(1)**
new current is same in both resistors **(1)** larger share of the 9 V **(1)**]

[or $V_{out} = V_{in} \frac{R_2}{R_1 + R_2}$ **(1)** R_1 decreases **(1)** V_{out} decreases **(1)**] 3

[7]

23. (a) Vrms = $(5 \times 10^{-3}) \times (2.0 \times 10^{3})$ = 10 (V) **(1)**
$V_{peak} = 10 \times \sqrt{2}$ = 14 V (14.1) **(1)**
[or correct value of I_{peak} to give V_{peak}] 2

(b) (i) period = $\frac{1}{f} = \frac{1}{50} = 20\,ms$ **(1)**

(ii) oscilloscope trace:
correct ac. waveform (for more than 1 cycle) **(1)**
correct peak value **(1)** (allow C.E. for value from (a))
correct period **(1)** (allow C.E. for value from (b)(i)) 4

[6]

24. (a) (i) $\in = I(R + r)$ **(1)**

(ii) $V_R = IR$ gives $V_R = \in - I_r$ **(1)** 2

(b) (i) $P = VI$ gives 30 = 120 I **(1)**
I = 0.25 A **(1)**

(ii) I through lamp = 0.25 (A) and p.d. across it = 240 V **(1)**
p.d. due to 1 cell = 1.5 – (0.25 × 1.2) = 1.2 (V) **(1)**

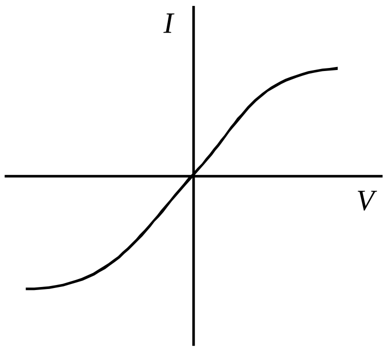
number of cells = $\frac{120}{1.2}$ = 100 **(1)**

[or R_L given by $30 = 0.25^2 R_L$ and R_L = 480 (Ω) **(1)**
$1.5n = 0.25(480 + 1.2n)$ **(1)**
$1.2n = 120$ and $n = 100$ **(1)**]

[or $\in = V + Ir$ gives $1.5n = 120 + 0.25 \times 1.2n$ **(2)**

n = 100 **(1)**]	5
	[7]

25. (a)



correct curve in positive quadrant **(1)**
correct curve in negative quadrant **(1)**
passing through origin **(1)**

3

(b) the current heats the filament **(1)**
(temperature rises) resistance increases **(1)**
pd. and current do not increase proportionally **(1)**
some reference to mirror image in negative quadrant **(1)**

max 3

QWC

(c) diagram to show:

battery, variable resistance (or variable supply) and filament **(1)**
current sensor in series circuit **(1)**
voltage sensor across filament **(1)**
the two sensor boxes connected to datalogger **(1)**

method:

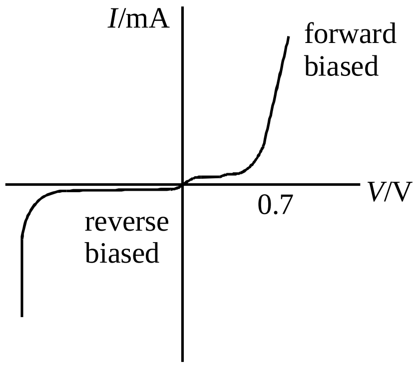
variable resistor or variable supply altered
[or choose recording interval] **(1)**
thus changing both *V* and *I* **(1)**

max 5

QWC

[11]

26. (a)



forward bias:
zero current rising gradually **(1)**
sharp increase at ≈ 0.7 V **(1)**

reverse bias:
zero or slightly less than zero current **(1)**
sharp negative increase at breakdown **(1)**
breakdown value >50 V indicated **(1)**

max 4

(b) forward bias: high resistance (initially gives small current) **(1)**
at ≈ 0.7 V, resistance decreases rapidly (current increases) **(1)**

reverse bias: high resistance (gives ≈ zero or slightly negative current) **(1)**
at breakdown, resistance ≈ zero (and very large current) **(1)**

max 3

QWC

[7]

27. (a) only 30 Ω in the circuit **(1)**
(use of $V = IR$ gives) $6 = I \times 30$ and $I = 0.20$ A **(1)** 2

(b) two resistors in parallel gives $\frac{1}{R} = \frac{1}{60} + \frac{1}{30}$ **(1)**

and R = 20 (Ω) **(1)**
total resistance = 20 + 30 = 50 (Ω) **(1)**
(allow C.E. for value of R)

$I = \frac{6}{50}$ = 0.12 A **(1)** (allow C.E for total resistance) 4

[6]

28. (a) (i) energy provided by the battery **(1)**
per unit charge **(1)**
[or potential difference across battery **(1)** when no current flows **(1)**]

(ii) when current flows, work is done inside the battery
to overcome the resistance (hence $V < \in$) **(1)**
(or any correct alternative) 3

(b) (i) suitable scale for *I* **(1)**
four correct points **(1)** **(1)**
best straight line **(1)**

(ii) ($\in = Ir + V$ gives) $V = -rI + \in$ **(1)**
intercept = $\in$ = 5 V **(1)**
gradient = (–)*r* **(1)**

$$= \frac{5}{0.35} = 14.(2)\ \Omega \textbf{ (1)}$$ 8

[11]