Anglo-Chinese Junior College

Physics Preliminary Examination
Higher 2

A Methodist Institution
(Founded 1886)

CANDIDATE NAME		CLASS	
CENTRE NUMBER	S	INDEX NUMBER	

PHYSICS **9646/02**

Paper 2 Structured Questions

27 Aug 2014
1 hour 45 minutes

Candidates answer on the Question Paper.
No Additional Materials are required

READ THESE INSTRUCTIONS FIRST

Write your Name and Index number in the spaces on all the work you hand in.
Write in dark blue or black pen.
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

Answer **all** questions.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

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1	/ 8
2	/ 7
3	/ 7
4	/ 8
5	/ 7
6	/ 7
7	/ 16
8	/ 12
Total	/ 72

For Examiner's Use

DATA AND FORMULAE

Data

speed of light in free space,	c	=	3.00×10^{8} m s^{-1}
permeability of free space,	μ_o	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space,	ε_o	=	8.85×10^{-12} F m^{-1} $(1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge,	e	=	1.60×10^{-19} C
the Planck constant,	h	=	6.63×10^{-34} J s
unified atomic mass constant,	u	=	1.66×10^{-27} kg
rest mass of electron,	m_e	=	9.11×10^{-31} kg
rest mass of proton,	m_p	=	1.67×10^{-27} kg
molar gas constant,	R	=	8.31 J K^{-1} mol^{-1}
the Avogadro constant,	N_A	=	6.02×10^{23} mol^{-1}
the Boltzmann constant,	k	=	1.38×10^{-23} J K^{-1}
gravitational constant,	G	=	6.67×10^{-11} N m^{2} kg^{-2}
acceleration of free fall,	g	=	9.81 m s^{-2}

Formulae

uniformly accelerated motion,	s	=	$ut + \frac{1}{2}at^2$
	v^2	=	$u^2 + 2as$
work done on/by a gas,	W	=	$p\,\Delta V$
hydrostatic pressure,	p	=	$\rho g h$
gravitational potential,	ϕ	=	$-\dfrac{Gm}{r}$
displacement of particle in s.h.m.,	x	=	$x_o \sin \omega t$
velocity of particle in s.h.m.,	v	=	$v_o \cos \omega t$
		=	$\pm\,\omega\sqrt{x_o^2 - x^2}$
mean kinetic energy of a molecule of an ideal gas	E	=	$\dfrac{3}{2}kT$
resistors in series,	R	=	$R_1 + R_2 + \ldots$
resistors in parallel,	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
electric potential,	V	=	$\dfrac{Q}{4\pi\varepsilon_o r}$
alternating current/voltage,	x	=	$x_o \sin \omega t$
transmission coefficient,	T	$\propto$	$\exp(-2kd)$
	where k	=	$\sqrt{\dfrac{8\pi^2 m(U-E)}{h^2}}$
radioactive decay,	x	=	$x_o \exp(-\lambda t)$
decay constant,	λ	=	$\dfrac{0.693}{t_{1/2}}$

For Examiner's Use

Answer **all** the questions in the spaces provided.

1 (a) Define *work*.

....

....

.... [1]

(b) Energy can be defined as the ability to do work.

In each of the following cases, state a possible object on which work may be done and explain how the law of conservation of energy can be applied.

An example of how the question should be answered is provided below.

Situation	**On what object is the work done?**	**Application of conservation of energy**
Car stopping without skidding from a speed of 40 m s^{-1}.	Work is done on the brakes.	Almost all of the kinetic energy becomes heat energy.
Steam engine where a constant mass of steam at constant pressure increases its volume.	[1]	[1]
Photocell / Light Dependent Resistor (LDR) in which light incident on a metal surface results in decrease in resistance.	[1]	[1]
Battery pushing charge through an electric chainsaw cutting a thick slab of wood.	[1]	[2]

For Examiner's Use

2 (a) (i) Given that the mass of an oxygen molecule is 5.3×10^{-26} kg, show that the root mean square (rms) speed for oxygen molecules in the atmosphere when the temperature is 23 °C is 480 m s^{-1}.

[1]

(ii) Explain why the rms speed of argon atoms in the atmosphere at 23 °C will be different from that of the oxygen molecules given in (i)

[1]

(b) The rms speed of hydrogen molecules at 23 °C is 1920 m s^{-1}. The escape velocity from the Earth is 11 000 m s^{-1}.

Explain why almost all the molecules of hydrogen that have ever been in the Earth's atmosphere have escaped into space but many oxygen molecules have remained in the atmosphere.

[2]

(c) Using the Kinetic model of gases, explain how gases exert a pressure on the sides of its container.

[3]

For Examiner's Use

3 **(a)** An electron is travelling at right angles to a uniform magnetic field of flux density 1.5 mT, as illustrated in Fig 3.1.

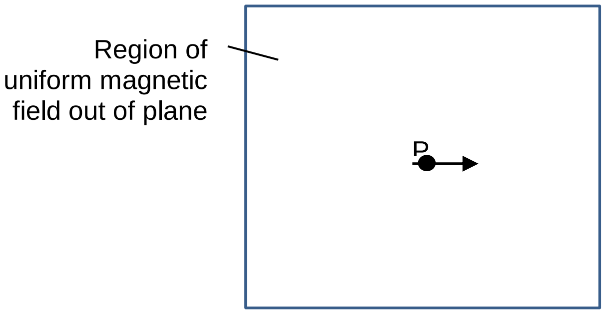

Fig 3.1

The magnetic field is acting <u>out</u> of the plane of the paper.
When the electron is at P, its velocity is 1.8×10^{7} m s^{-1} in the direction shown. This is normal to the magnetic field.

(i) On Fig 3.1, sketch the path of the electron, assuming that it does not leave the region of the magnetic field. [1]

(ii) **1.** Show that the force on the electron due to the magnetic field is

4.32×10^{-15} N.

[1]

2. Hence calculate the radius of the electron's path.

radius = ……………………….. m [3]

(b) A uniform electric field is now produced in the same region and in the opposite direction to the magnetic field. Suggest the shape of the resultant path of the electron and draw a sketch to illustrate the path.

……………………………………………………………………………………………………

…………………………………………………………………………………………………… [2]

For Examiner's Use

4 **(a)** Explain what is meant by the term *interference*.

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.... [2]

(b) A Kundt's tube is an experimental acoustical instrument that serves to measure the speed of sound in different medium.

It comprises of a long horizontal tube, containing a fine powder, which is closed at one end. A loudspeaker connected to a signal generator is positioned at the other end. The device is shown in Fig 4.1 and the signal generator is set to a frequency of 400 Hz.

From the *interference* of waves resulting in stationary waves being formed, an interesting pattern can be observed as seen in Fig 4.1.

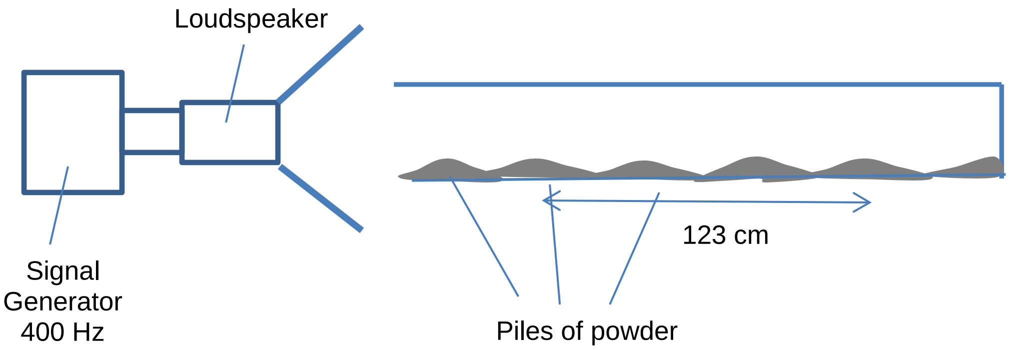

Fig 4.1

(i) Label the positions of nodes (**N**) and antinodes (**A**) on Fig. 4.1 [1]

(ii) Explain the formation of the piles of fine powder at the positions shown on Fig 4.1.

....

....

....

.... [3]

(iii) Hence or otherwise, determine the speed of the sound waves in that medium.

Speed of Sound = ... m s^{-1} [2]

For Examiner's Use

5 **(a)** Stimulated emission and spontaneous emission are two processes in which photon emissions can take place.

Explain the main difference between how these processes can happen.

.... [1]

(b) State and explain the importance of stimulated emission in the production of lasers.

....

....

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.... [2]

(c) Explain what is meant by population inversion and why is it an essential condition in laser production.

....

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.... [2]

For Examiner's Use

5 (d) Fig 5(a) shows the energy level diagram of a **three-level laser**. Lasing takes place between E_2 and E_1 while Fig 5(b) shows the energy level diagram of a **four-level laser**. Lasing takes place between E_3 and E_2.

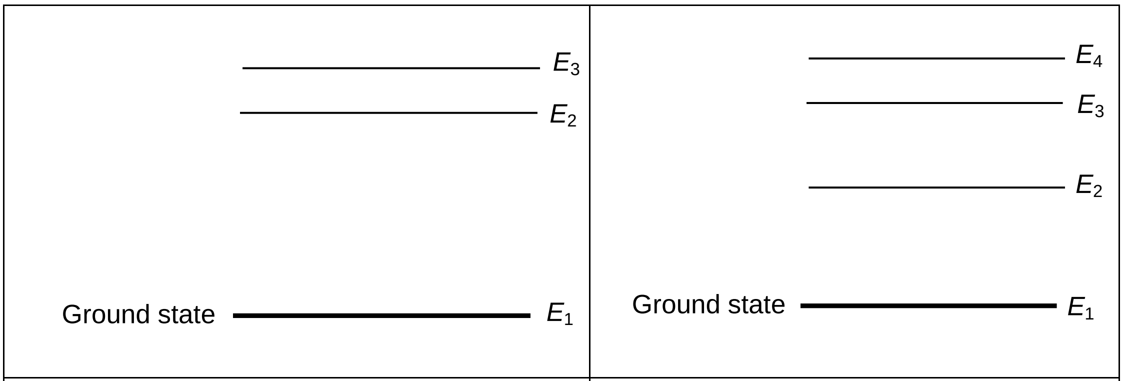

Fig 5(a) | Fig 5(b)

State the advantage of the four-level laser over the three-level laser.

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.... [2]

For Examiner's Use

6 (a) Thoron is a radioactive gas. The variation with time t of the detected count rate C from a sample of the gas is shown in Fig. 6.1

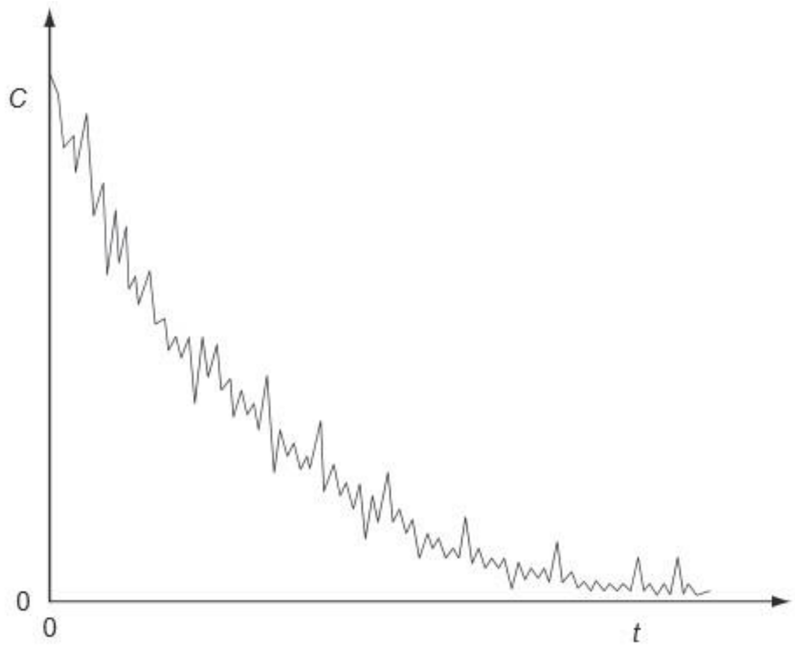


Fig 6.1

(i) Radioactive decay is said to be a *random* and *spontaneous* process.

State the feature of Fig 6.1 which indicates that the process is *random*.

....

....

....

.... [1]

(ii) A second similar sample of thoron is prepared but it is at a much higher temperature. The variation with time of the count rate for this second sample is determined.

State the expected feature of the decay curve for the second sample, with reference to Fig 6.1 that suggests that radioactive decay is a spontaneous process.

....

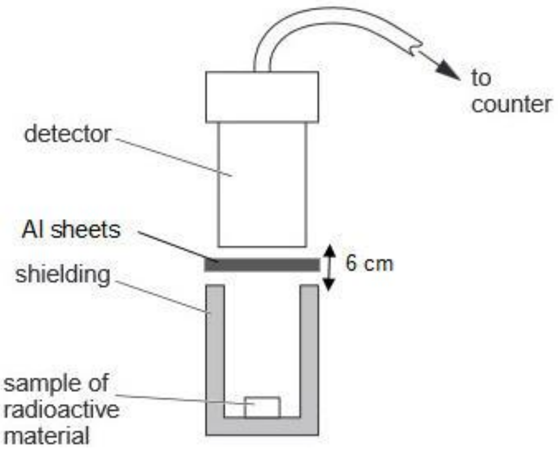
....

....

.... [1]

6 (b) In order to identify the radioactive particles emitted by a given sample of radioactive isotope, a student set up the apparatus as illustrated in Fig 6.2 and vary the thickness of Al sheets used.

The separation from the window of the detector from the shielding is about 6 cm.



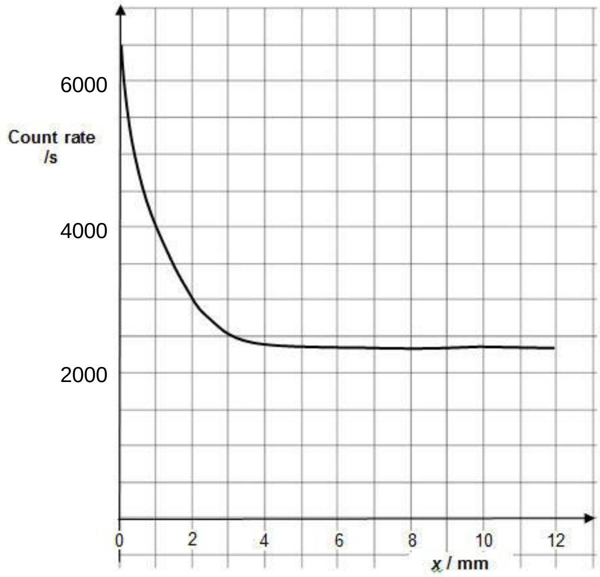


Fig 6.2 **Fig 6.3**

Fig 6.3 is the best fit line showing the variation of the count rate with the thickness *x* of Al sheets used.

The count rate plotted in Fig 6.3 is after accounting for background count.

(i) Explain why this experiment cannot provide evidence to show the presence of alpha particles.

....

....

.... [1]

(ii) Indicate the evidence from Fig 6.3 that indicates the presence of

1. *beta* particles

....

....

.... [1]

2. *gamma* particles

....

....

.... [1]

For Examiner's Use

6 **(c)** A *point* source of alpha particles $^{241}_{95}Am$ with decay constant 4.80 x 10^{-11} s^{-1} is mounted 7.0 cm in front of a Geiger Muller(GM) tube whose mica window has a receiving area of 3.0 cm^2, as shown in Fig 4. The whole setup is enclosed in a **vacuum** enclosure.

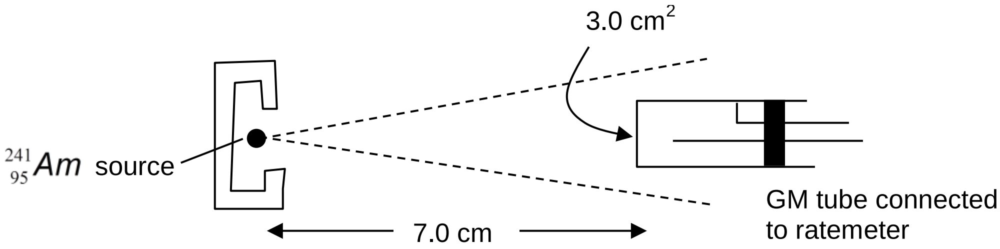


Fig 4

The counter linked to the GM tube records 5.4 x 10^4 counts per minute.

(i) Show that the activity of the source is 18.5 x 10^4 s^{-1}

[1]

(ii) Hence determine the number of $^{241}_{95}Am$ atoms in the source.

Number of atoms = …………… [1]

For Examiner's Use

7 (a) Niels Bohr presented a new model of the hydrogen atom in 1913. Bohr combined ideas from Planck's original quantum theory, Einstein's concept of the photon, Rutherford's planetary model of the atom and Newtown mechanics to arrive at a model of the hydrogen atom. He postulated that the electron moves in circular orbit around the proton under the influence of the electric force of attraction as shown in Fig. 7.1. The atom emits radiation when the electron makes a transition from a more energetic initial state to a lower-energy stationary state.

The approximation is made such that the proton is so much massive than the electron that it can be regarded as stationary. The smallest radius of the orbit *r* is 5.29 x 10^{-11} m.

Bohr postulated that the angular momentum of the electron was quantised and predicted that the allowable energies of the hydrogen atom are given by

$$E_n = -\frac{13.6}{n^2} \text{ eV} \quad \text{where } n = 1, 2, 3\ldots \text{ ------------- equation (1)}$$

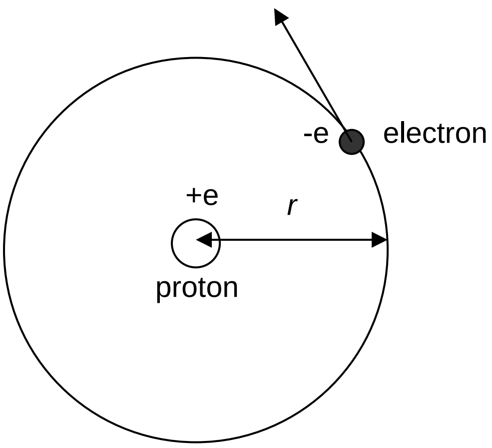


Fig. 7.1

(i) Considering the forces acting on an electron,

1. show that the momentum *p*, of an electron in an orbit of radius *r* is given by

$$p = \sqrt{\frac{me^2}{4\pi\varepsilon_o r}}$$

[2]

2. hence, determine the magnitude of the momentum of the electron when in orbit of radius *r* = 5.29 x 10^{-11} m.

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

7 (a) (ii) Hence explain, how this model of the hydrogen, where the electron orbits in a circular path of a fixed radius, violates the Heisenberg uncertainty principle.

....

....

.... [1]

(b) When high-energy electrons or any other charged particles bombard a metal target, x-rays are emitted. The x-ray spectrum typically consists of a broad continuous band containing a series of sharp lines which is due to bremsstrahlung radiation. Characteristics x-rays occurs when a bombarding electron collides with a target atom. The electrons have sufficient energy to remove an inner-shell electron from the atom. The vacancy created in the shell is filled when an electron in a higher level drops down into the level containing the vacancy.

A diagram showing the origin of the K_α, K_β and other peaks are as shown in Fig. 7.2 below.

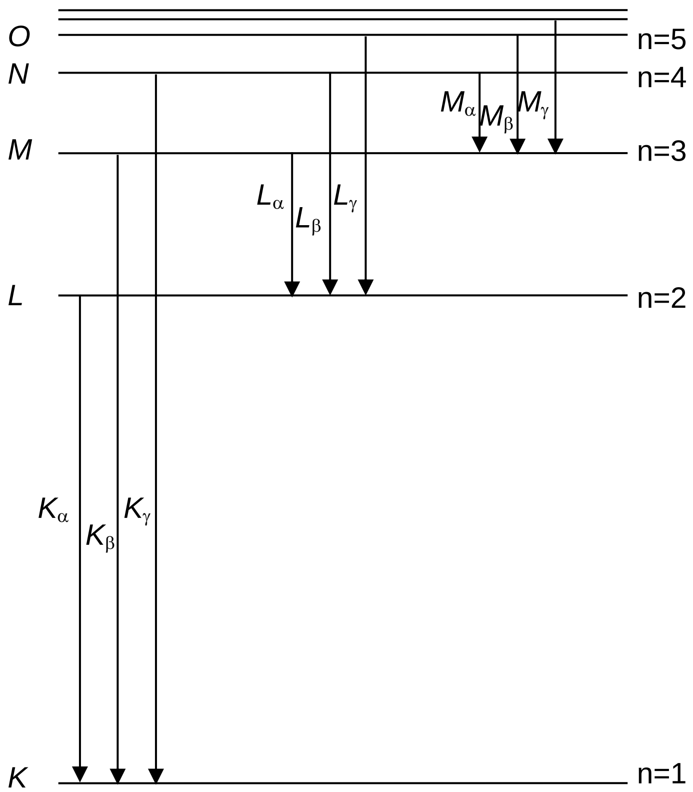


Fig. 7.2

For a multi-electron atom, because of the presence of one k-shell electron, the other electron will 'see' an effective nuclear charge of approximately (Z - 1)e, where e is the elementary charge and Z is the atomic number of the element.

As such equation 1 in **(a)** can be approximated as $E_n = -\dfrac{(13.6\ eV)(Z-1)^2}{n^2}$.

For an electron that makes a transition from the *L* shell (with n = 2) to the *K* shell (with n = 1),

(i) express the energy change in terms of *Z*,

[2]

(ii) hence, derive the relationship between the frequency *f* of the K_α radiation and *Z.*

[2]

(c) It is thought that the wavelength λ of K_α x-ray radiation, varies with atomic number of element *Z* according to the expression below as suggested by Mosley in 1914.

$$\sqrt{\frac{1}{\lambda}} = A\left(Z - B\right)$$ where *A* and *B* are constants

The frequency *f* of K_α x-ray radiation, of a few elements are given in Fig. 7.3.

Element	Atomic number *Z*	Frequency *f* / 10^{18} Hz	$\sqrt{\frac{1}{\lambda}}$ / $10^4\,\text{m}^{-1/2}$
Titanium	22	1.08	6.01
Chromium	24	1.30	6.59
Iron	26	1.54	7.16
Nickel	28	1.79	
Zinc	30	2.07	8.30
Gallium	31	2.21	8.59

Fig. 7.3

(i) Complete Fig. 7.3 for Nickel. [1]

7 (c) (ii) The data from Fig. 7.3 are used to plot the graph of Fig. 7.4.

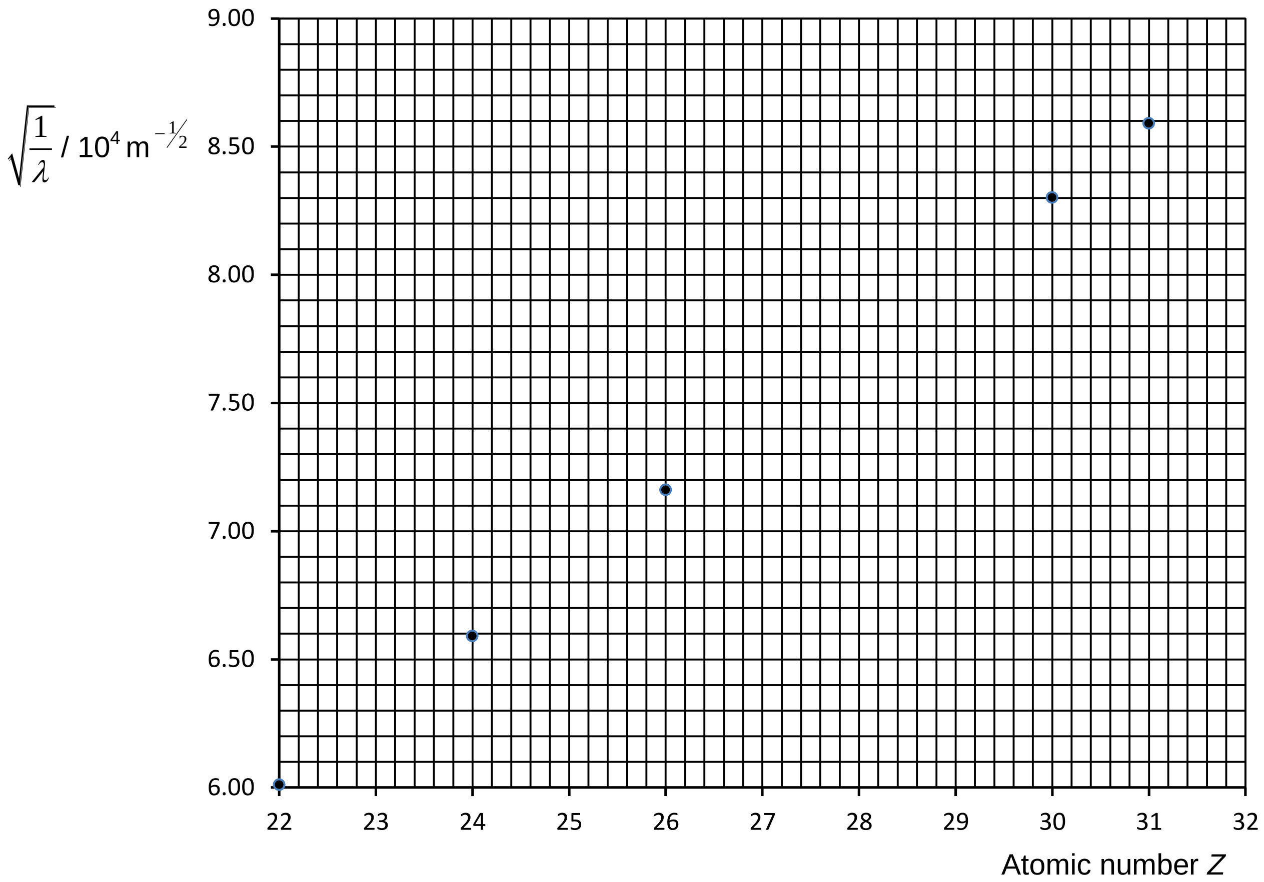


Fig. 7.4

On Fig. 7.4,

1 Plot the point corresponding to Nickel. [1]
2 Draw the best-fit line for all the points. [1]

(iii) Use the line drawn in **(ii)** to determine the magnitude of the constants A and B in the expression in **(c)**.

A = ... m$^{-\frac{1}{2}}$

B = ... [3]

For Examiner's Use

7 (d) One of the possible use for characteristic spectrum is to allow impurity in specimens to be detected by scientists. A cobalt target is bombarded with electrons, and the wavelengths of its characteristic x-ray spectrum are measured. There is also a second fainter characteristic spectrum, which is due to an impurity in the cobalt. The wavelengths of the K_α lines are 178.9 pm (cobalt) and 143.5 pm (impurity), and the atomic number Z for cobalt is 27.

Using Fig. 7.3, deduce the impurity in the cobalt.

[2]

For Examiner's Use

8 The exact relationship between the temperature of an object and the amount of radiation emitted has been explored by a number of famous physicists. In 1879, the law that describes this relationship was first experimentally discovered Josef Stefan. Shortly later, Ludwig Boltzmann derived it theoretically.

The relationship between the power radiated P_{rad} by an object of temperature T (in kelvin), independently formulated by Stefan and Boltzmann states that

$$P_{rad} = \varepsilon \sigma A T^4$$

where ε is the emissivity of the object
σ is the Stefan-Boltzmann constant and
A is the surface area of the object

The emissivity constant depends on the material of the object.

For practical purposes, the net power being radiated is more useful than the absolute radiated power. The net power radiated by an object at temperature T in an environment T_0 is given by

$$P_{net} = P_{rad} - P_{absorb}$$

This leads to

$$P_{net} = \varepsilon \sigma A T^4 - \varepsilon \sigma A T_0^4$$

For a given radiating body ε, σ and A are constant and if the room temperature T_0 (295K) is much lower than the object's temperature T (ranged from 1500 to 2000K), then P_{rad} is much greater than P_{absorb}. We can then assume that for a given radiating body power radiated is given by

$$P \alpha T^4$$

Design a laboratory experiment to investigate how the power P radiated from a tungsten lamp at high temperature varies with its thermodynamic temperature T.

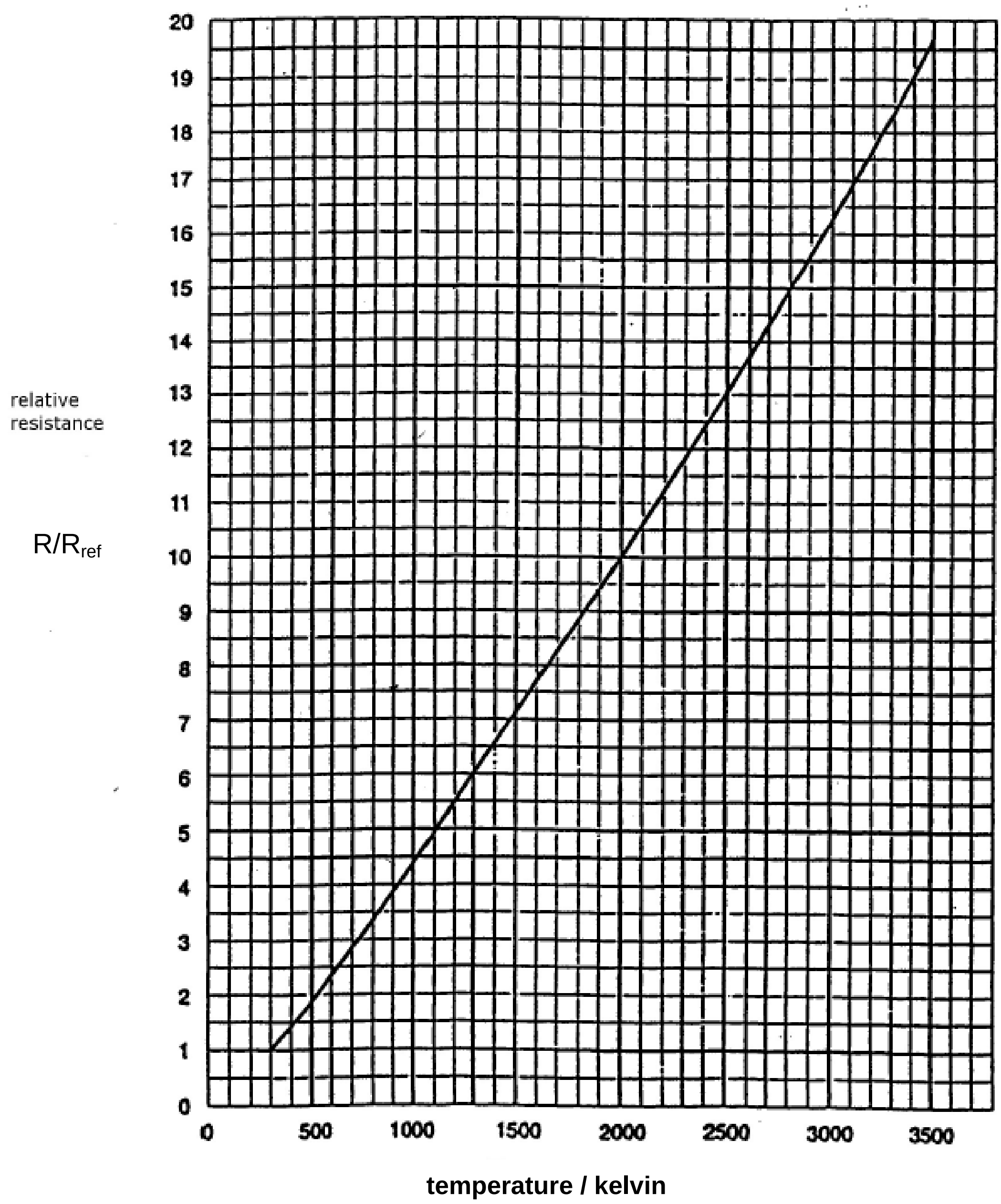
The equipment available includes the following:

Leads/ connecting wires
12 V 400 W Tungsten filament bulb
A variable power supply 13 V MAX
Radiation detector
Voltmeter
Ammeter
Rheostat
Digital multimeters
Metre rule
Retort stand, boss and clamp
Thermocouple
Platinum Resistance thermometer

Data showing the temperature dependence of relative resistance for tungsten and resistivity of tungsten as a function of temperature are provided and are shown in **Fig 8.1** and **Fig 8.2** respectively.

For Examiner's Use

Fig 8.1: Temperature dependence of relative resistance for tungsten



For Examiner's Use

Fig 8.2 Resistivity of tungsten as a function of temperature

R/R_{ref}	Temperature / K	Resistivity / $\mu\Omega$ cm
1.00	300	5.65
1.43	400	8.06
1.87	500	10.56
2.34	600	13.23
2.85	700	16.09
3.36	800	19.00
3.88	900	21.94
4.41	1000	24.93
4.95	1100	27.94
5.48	1200	30.98
6.03	1300	34.08
6.58	1400	37.19
7.14	1500	40.36
7.71	1600	43.55
8.28	1700	46.78
8.86	1800	50.05
9.44	1900	53.35
10.03	2000	56.67
10.63	2100	60.06
11.24	2200	63.48
11.84	2300	66.91
12.46	2400	70.39
13.08	2500	73.91
13.72	2600	77.49
14.34	2700	81.04
14.99	2800	84.70
15.63	2900	88.33
16.29	3000	92.04
16.95	3100	95.76
17.62	3200	99.54
18.28	3300	103.3
18.97	3400	107.2
19.66	3500	111.1
26.35	3600	115.0

For Examiner's Use

You may also use any of the other equipment usually found in a Physics laboratory.

You should draw a labelled diagram to show the arrangement of your apparatus. In your account you should pay attention to

(a) The identification and control of variables,

(b) the equipment you would use,

(c) the procedure to be followed,

(d) how the power radiated from a tungsten lamp could be determined ,

(e) any precautions that you would take to improve the accuracy and safety of the experiment.

Diagram

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For Examiner's Use

For Examiner's Use

[12]

End of paper