A2

OCR
Oxford Cambridge and RSA

A Level Physics B (Advancing Physics)
H557/01 Fundamentals of physics
Sample Question Paper

Date – Morning/Afternoon
Time allowed: 2 hours 15 minutes

You must have:
- the Data, Formulae and Relationships Booklet

You may use:
- a scientific calculator

First name	SA										
Last name											
Centre number	2	5	2	7	8	**Candidate number**					

INSTRUCTIONS
- Use black ink. You may use an HB pencil for graphs and diagrams.
- Complete the boxes above with your name, centre number and candidate number.
- Answer **all** the questions.
- Write your answer to each question in the space provided.
- Additional paper may be used if required but you must clearly show your candidate number, centre number and question number(s).
- Do **not** write in the bar codes.

INFORMATION
- The total mark for this paper is **110**.
- The marks for each question are shown in brackets **[ ]**.
- Quality of extended responses will be assessed in questions marked with an asterisk (*).
- This document consists of **32** pages.

SECTION A

You should spend a maximum of 40 minutes on this section.

Answer **all** the questions.

1 The isotope of radon $^{220}_{86}\text{Rn}$ decays by a series of transformations to a final stable product. The particles emitted during the transformations are $\alpha,\ \alpha,\ \beta,\ \beta,\ \alpha$.

Which of the isotopes below is the final product of the decay series?

A $^{206}_{82}\text{Pb}$

B $^{207}_{82}\text{Pb}$

C $^{208}_{82}\text{Pb}$

D $^{212}_{84}\text{Po}$

$3 \times {}^{4}_{2}\text{He} = {}^{12}_{6}$ $\quad 2 \times {}^{0}_{-1}\beta = {}^{0}_{-2} \rightarrow {}^{12}_{4}$

$220 - 12 = 208$
$86 - 4 = 82$ Pb

Your answer C

[1]

2 An imagined atom can exist in five energy levels. Transitions between all levels are possible.

Which statement about the imagined atom is correct?

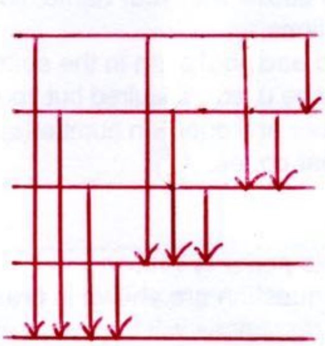
A When the atom jumps to a lower level an electron gains energy.

B When the atom emits a photon the atom jumps to a higher energy level.

C There will be six frequencies in the line spectrum of the atom.

D There will be ten frequencies in the line spectrum of the atom.

Your answer D



10 possible transitions so 10 frequencies

[1]

3 A proton is accelerated until its total energy is double its rest energy.

What is its speed, expressed in terms of the speed of light, c?

$E_{TOTAL} = \gamma E_{REST}$

$\gamma = 2$

$2 = 1 / \sqrt{1 - v^2/c^2}$

$0.5^2 = 1 - v^2/c^2$

$v^2/c^2 = 0.75$

$v = \sqrt{0.75}\, c = 0.87c$

A 0.25c

B 0.50c

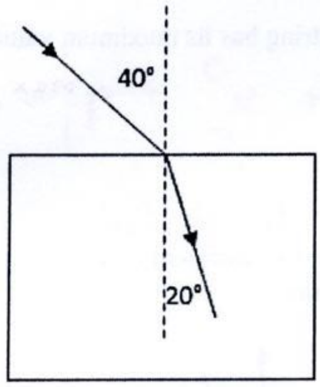
C 0.75c

D 0.87c

Your answer D

[1]

4 A ray of light passes from air into a rectangular glass block.



The refractive index of the glass is

$n = \frac{\sin i}{\sin r} = \frac{\sin 40}{\sin 20} = 1.88$

A 0.53

B 0.82

C 1.2

D 1.9

Your answer D

[1]

5 The solid line shows the standing wave pattern of a vibrating string which is fixed at ends X and Y. The broken line shows the position of the string half a cycle later. The displacement at point Q is a maximum.

Which one of these statements is true?

A The distance from P to R is one wavelength. no its $\lambda/2$

B A short time later, the string at R will move up. no its at a node

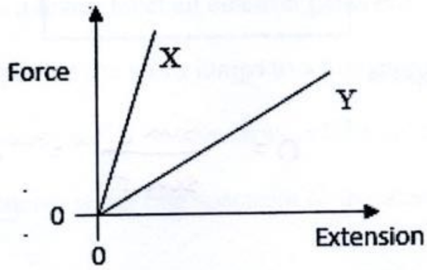
C The lowest possible frequency for this string is one third of its current value. YES as λ can be 3x larger

D The kinetic energy of the string has its maximum value. No its minium max is at undisturbed position

Your answer C

[1]

6 This is a force–extension graph for two different materials, X and Y. The materials are stretched up to the point at which they fracture.



Which one of these statements about the materials is true?

A Y is stiffer than X No X is stiffer (higher gradient)

B both materials are tough No – there is no plastic deformation

C X stores more energy than Y No area under graph is less

D X and Y obey Hooke's law Yes $F \propto x$ – straight lines

Your answer D

[1]

7 Source **A** is a radioisotope with a half-life of 2 hours. Source **B** is a radioisotope with a half-life of 4 hours.
The initial activity of source **A** is twice that of source **B**.

How long will pass before the activity of source **B** is twice that of source **A**?

t/h	0	2	4	6	8	10	12

ACTIVITY
A: 2 → 1 → 0.5 → 0.25 → 0.125
B: 1 —$t_{1/2}$→ 0.5 —$t_{1/2}$→ 0.25
1 : 2

A 4 hours

B 6 hours

C 8 hours

D 12 hours

Your answer C

[1]

8 Here is the equation for beta decay:

$$ {}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu} $$

Which of the following quantities is/are conserved.

1 number of quarks ✓

2 lepton number ✓

3 charge number ✓

A 1, 2 and 3

B Only 1 and 2

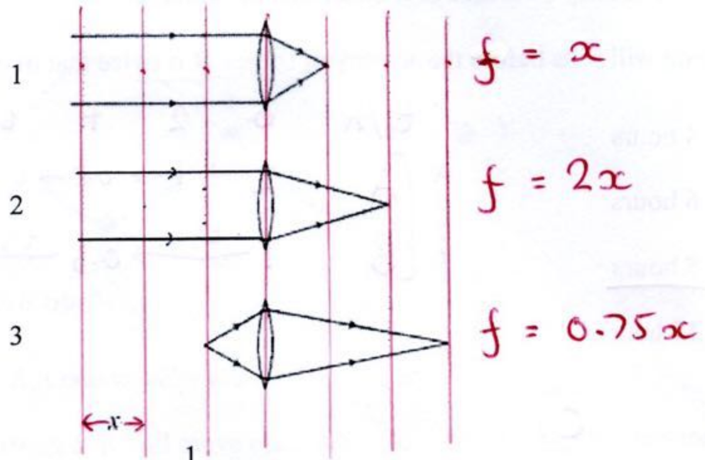
C Only 2 and 3

D Only 1

Your answer A

[1]

9 The diagrams 1, 2 and 3 show three different lenses forming images.
In each diagram, the dotted lines are equally-spaced and separated by the same distance x.



Which, if any, of the lenses have power $P = \dfrac{1}{x}$?

A None

B lens 1

C lens 2

D lens 3

Your answer B

[1]

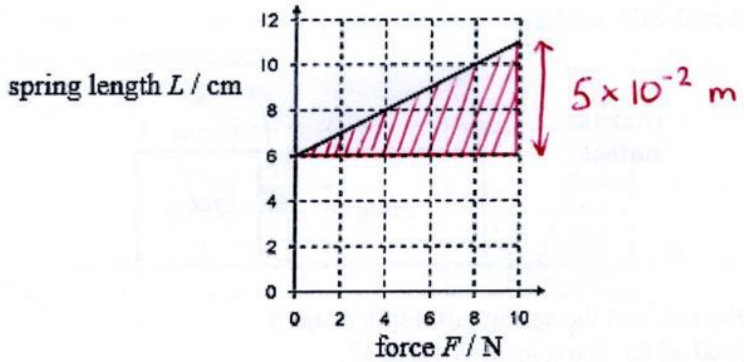
③ $\frac{1}{v} = \frac{1}{u} + \frac{1}{f}$

$\therefore \frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{3x} - \frac{1}{-x} = \frac{1}{3x} + \frac{3}{3x}$

$= \frac{4}{3x}$

$\therefore f = \frac{3}{4}x$

10 The graph shows the variation of length L of a spring with the stretching force F.



Which is the best estimate of the work done in stretching the spring over the range given by the graph?

A 0.25 J

B 0.85 J

C 85 J

D 200 J

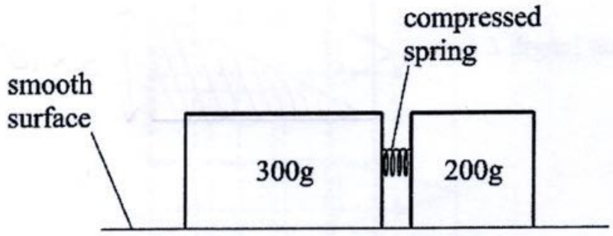
Area under graph $= 10\text{N} \times \frac{5 \times 10^{-2}}{2}$

$= 0.25$ J

Your answer A

[1]

11 The diagram shows two blocks of different masses resting on a smooth surface. They are held together so that a spring between them is in compression.



The blocks are released, and the spring pushes them apart.
The maximum speed of the 200 g mass is 4.2 m s^{-1}.

What is the maximum speed of the 300 g mass?

A 6.3 m s^{-1}

B 2.1 m s^{-1}

C 2.8 m s^{-1}

D 1.4 m s^{-1}

momentum is conserved

$300v = 200 \times 4.2$

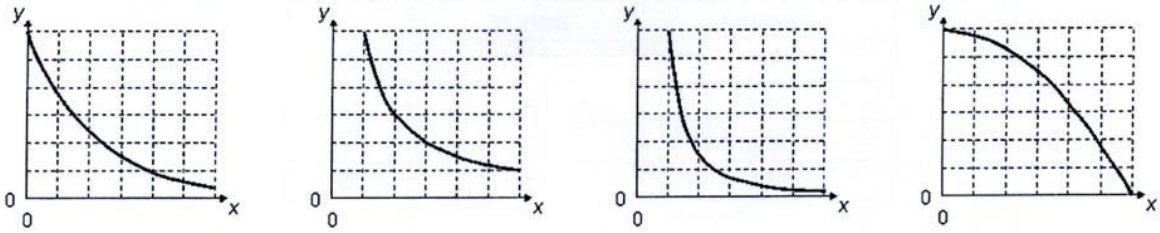
$v = \frac{200}{300} \times 4.2 = 2.8 \text{ ms}^{-1}$

Your answer C

[1]

The following information is for use in questions **12** and **13**.

The graphs **A**–**D** represent different relationships between variables. The dotted lines mark out equal intervals along the x- and y-axes.



A **B** **C** **D**

12 Which graph **A**, **B**, **C**, or **D** best represents the relationship between the variables x and y where:

y is the pressure of a fixed mass of gas at room temperature
x is the volume occupied by that gas.

$p \propto \frac{1}{V}$ $\therefore$ $y = \frac{1}{x}$ graph

Your answer B

[1]

13 Which graph **A**, **B**, **C**, or **D** best represents the relationship between the variables x and y where:

y is the electric field strength in the space surrounding a point change
x is the distance from the point charge.

$E = \frac{kQq}{r^2}$ $\therefore$ $y = \frac{1}{x^2}$ graph

Your answer C

[1]

14 Four different ions enter a region of uniform magnetic field. Each ion enters with the same velocity. The magnetic field acts at 90° to the path of the ions. Each ion is defined below in terms of its nucleon number and charge.

Which ion will travel in a circular path with the largest radius?

m/q		nucleon number m	charge q
1	**A**	1	1
2	**B**	2	1
3	**C**	3	1
3.5	**D**	7	2

$Bqv = \frac{mv^2}{r}$ $\therefore$ $r = \frac{mv}{Bq}$

Your answer D

$r \propto m/q$

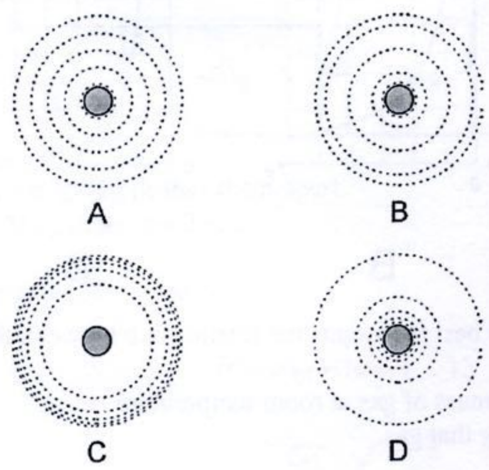
[1]

15 Here are four diagrams of possible equipotentials near an isolated star.
In each diagram, the difference in gravitational potentials between adjacent equipotentials is the same.

Which diagram is correct?

$V_{grav} \propto -1/r^2$

so



Your answer D

[1]

16 A satellite orbits the Earth in a circular orbit of height 2.3×10^6 m above the ground.

What is the angular velocity ω of the satellite?

$r = 2.3 + 6.4 \times 10^6 = 8.7 \times 10^6$ m

radius of Earth = 6.4×10^6 m.
mass of Earth = 6.0×10^{24} kg

$a = \omega^2 r = \frac{GM}{r^2}$

A 6.1×10^{-7} rad s^{-1}

B 3.3×10^{-5} rad s^{-1}

C 7.8×10^{-4} rad s^{-1}

D 5.7×10^{-3} rad s^{-1}

$\omega = \sqrt{\frac{GM}{r^3}}$

Your answer C

$= \sqrt{\frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{(8.7 \times 10^6)^3}} = 7.8 \times 10^{-4}$ rad s^{-1}

[1]

17 The up quark (u) has charge +⅔e and the down quark (d) a charge of −⅓e.

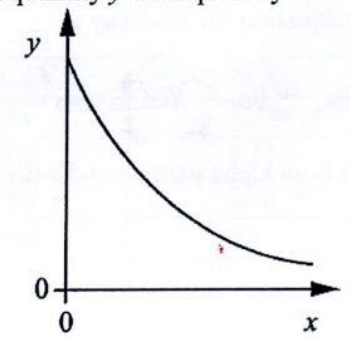
What is the correct combination of quarks that make up the proton and the neutron?

	proton (+1)	neutron (0)
A	ddd	uud
B	udd	uud
C	uud	udd
D	ddd	udd

Your answer C

[1]

18 The graph shows the variation in quantity *y* with quantity *x*.



Which pair(s) of quantities produce a similar graph?

1 mass remaining of a radioisotope (*y*) against time (*x*) ✓

2 charge (*y*) on a capacitor against potential difference (*x*) across the capacitor × $Q \propto V$

3 gravitational field strength from a point mass (*y*) against distance from mass (*x*) × $1/x$ graph

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer D

[1]

19 Two small metal spheres have the same electric charge. The distance between the centres of the spheres is 12 cm. The force on each sphere is 0.29 mN.

What is the electric charge on each sphere?

$F = \frac{kQq}{r^2} = \frac{kQ^2}{r^2}$ if $Q = q$

$\therefore Q^2 = \frac{Fr^2}{k}$ & $Q = \sqrt{\frac{Fr^2}{k}}$

$Q = \sqrt{\frac{0.29\times10^{-3} \times 0.12^2}{9\times10^9}} = 2.15\times10^{-8}$ C

A 4.6×10^{-16} C

B 4.6×10^{-9} C

C 2.2×10^{-8} C

D 6.8×10^{-5} C

Your answer C

[1]

20 $^{210}_{84}\text{Po}$ is a radioactive isotope. The equation for its decay is:

$$^{210}_{84}\text{Po} \rightarrow {}^{206}_{82}X + {}^{4}_{2}\alpha + \gamma$$

Where X is the daughter nucleus, α is an alpha particle and γ is a gamma photon.

What is the atomic number of X?

A 80

B 82

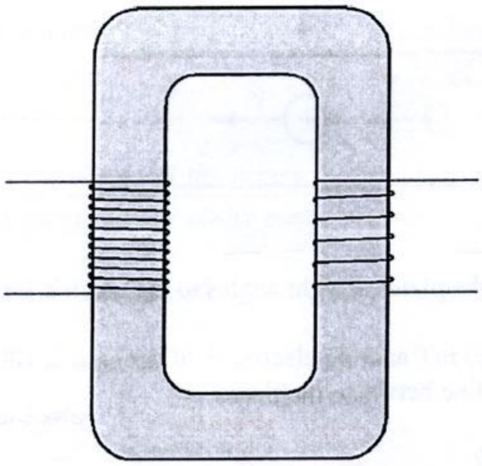
C 85

D 208

Your answer B

[1]

21 The diagram shows an ideal transformer.



also 50 Hz
$P \approx 120W \therefore I = 120/44 = 2.73A$
$V = 220 \times \frac{160}{800} = 44V$

Which of the following data sets about the output of the secondary coil is correct?

	p.d. / V	I / A	f / Hz
A	44.0 ✓	2.73 ✓	10.0
B	44.0 ✓	0.11	50.0 ✓
C	44.0 ✓	2.73 ✓	50.0 ✓ ←
D	1100	0.11	50.0 ✓

Your answer C

[1]

22 A 4700 μF capacitor is discharged through a 2200 Ω resistor. To the nearest second, how long will it take for the charge on the capacitor to fall to half its original value?

A 3 s

B 5 s

C 7 s

D 10 s

$Q = Q_0 e^{-t/RC}$

$\frac{1}{2} = e^{-t/RC}$

$\ln 2 = t_{\frac{1}{2}}/RC$

$\therefore t_{\frac{1}{2}} = \ln 2\, RC =$

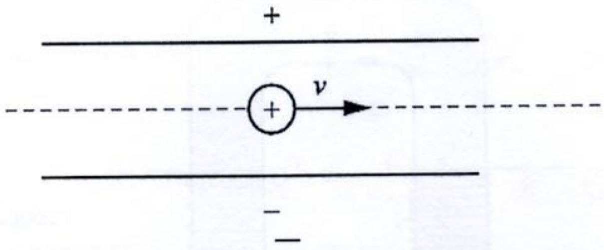
$= \ln 2 \times 2200 \times 4700 \times 10^{-6}$

$= 7.17s$

Your answer C

[1]

23 A proton enters the space between two oppositely charged parallel metal plates.



A magnetic field acts between the plates at right angles to the electric field and the direction of motion of the proton.
The magnetic field strength is 20 mT and the electric field strength is 100 V m^{-1}.
The proton moves in a straight line between the plates.

What is the speed of the proton?

magnetic electric
$F = Bqv = Eq$

$\therefore v = E/B = 100/20\times10^{-3}$

$= 5000\ ms^{-1}$

A 2000 m s^{-1}

B 5000 m s^{-1}

C 5 m s^{-1}

D 2 m s^{-1}

Your answer B

[1]

24 Here are some data about a volume of an ideal gas:

volume = 0.5×10^{-3} m^3
pressure = 0.25 MPa
temperature = 30 °C

What is the number of particles in the volume of gas?

A 3×10^{20}

B 3×10^{21}

C 3×10^{22}

D 3×10^{23}

$pV = NkT$

$\therefore N = pV/kT$

$= \dfrac{0.25\times10^{6} \times 0.5\times10^{-3}}{1.38\times10^{-23} \times (273+30)}$

$= 3\times10^{22}$

Your answer C

[1]

The following information is for use in questions **25** and **26.**

A proton ${}^{1}_{1}p$ and a ${}^{4}_{2}\text{He}$ nucleus (alpha particle) are both accelerated from rest through a potential difference of 1000 V.

$V = E/Q \therefore E = VQ$, $E \propto Q$ $p = +1$, $He = +2$

25 What is the ratio $\dfrac{\textit{kinetic energy of the proton}}{\textit{kinetic energy of the alpha particle}}$?   1 / 2

A $\frac{1}{4}$

B $\frac{1}{2}$

C $\frac{2}{1}$

D $\frac{4}{1}$

Your answer B

[1]

26 What is the ratio $\dfrac{\textit{momentum of the proton}}{\textit{momentum of the alpha particle}}$?

$v = \sqrt{\frac{2E_K}{m}}$

A $\frac{1}{2\sqrt{2}}$

B $\frac{1}{\sqrt{2}}$

C $\frac{\sqrt{2}}{1}$

D $\frac{2\sqrt{2}}{1}$

	mass	E_K	v	$p = mv$
proton	1	1	1	1
alpha	4	2	$\sqrt{2/4} = 1/\sqrt{2}$	$4/\sqrt{2}$ =

$\frac{\text{proton}}{\text{alpha}} = \frac{1}{4/\sqrt{2}} = \frac{\sqrt{2}}{4} = \frac{1}{2\sqrt{2}}$

Your answer A

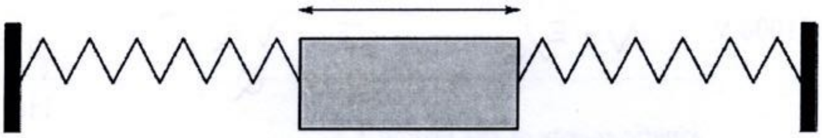
OR

$p = mv \therefore p^2 = m^2v^2$ **[1]**

$\therefore E_K = p^2/2m \therefore p = \sqrt{2mE_K}$ $\propto$ $m = \times 4$ $E_K = \times 2$

$\therefore p = \times\sqrt{8}$ so ratio $= 1/\sqrt{8} = 1/2\sqrt{2}$

27 A mass M oscillates in simple harmonic motion between two fixed supports. Frictional effects can be ignored. The time period of the oscillation is T_1.



The mass is replaced with a mass of 4 M **and** the amplitude of the oscillation is doubled. The new time period is T_2.

↳ no change

Which is the correct statement?

A $T_2 = 4\,T_1$

B $T_2 = 2\,T_1$

C $T_2 = T_1$

D $T_2 = \frac{1}{2}\,T_1$

$T = 2\pi\sqrt{\frac{m}{k}}$

so $T \times \sqrt{4} = 2\times$

$T_2 = 2T_1$

Your answer B

[1]

28 The activation energy E_A for the conduction of a semiconductor diode is 0.14 eV. The operating temperature of the diode in a circuit is measured at 85 ± 4 °C. A student is considering the effect this uncertainty causes in the calculation of the Boltzmann factor $e^{-E_A/kT}$.

Which of the following statements is/are true?

1 The % uncertainty in the Boltzmann factor will be the same as in the temperature. × exponential function

2 Temperatures should be expressed on the absolute scale in Kelvins for calculations with the Boltzmann factor. YES

3 The % uncertainty in T is 1.5% to two significant figures.

$4/85 \times 100 = 4.7\%$ so ×

$BF = e^{-E_A/kT}$

A 1, 2 and 3 are correct

B Only 1 and 2 are correct

C Only 2 is correct

D Only 1 is correct

Your answer C

[1]

The following information is for use in questions **29** and **30**.

The ratio of masses $\frac{M_{\text{Earth}}}{M_{\text{Moon}}} \approx 80$ and the ratio of radii $\frac{r_{\text{Earth}}}{r_{\text{Moon}}} \approx 4$.

29 What is the best estimate of the ratio of gravitational fields at the surface of the two bodies $\frac{g_{\text{Earth}}}{g_{\text{Moon}}}$?

$g = \frac{-GM}{r^2}$ Earth $\frac{\times 80}{\times 4^2} = \times \frac{80}{16} = 5$

A 1.6

B 5

C 20

D 320

Your answer B

[1]

30 What is the best estimate of the ratio of gravitational potentials at the surface of the two bodies $\frac{V_{\text{Earth}}}{V_{\text{Moon}}}$?

$V = \frac{-GM}{r}$ Earth $\frac{\times 80}{\times 4} = \times 20$

A 1.6

B 5

C 20

D 320

Your answer C

[1]

SECTION B

Answer **all** the questions.

31 **Fig. 31.1** shows a simple potential divider circuit.

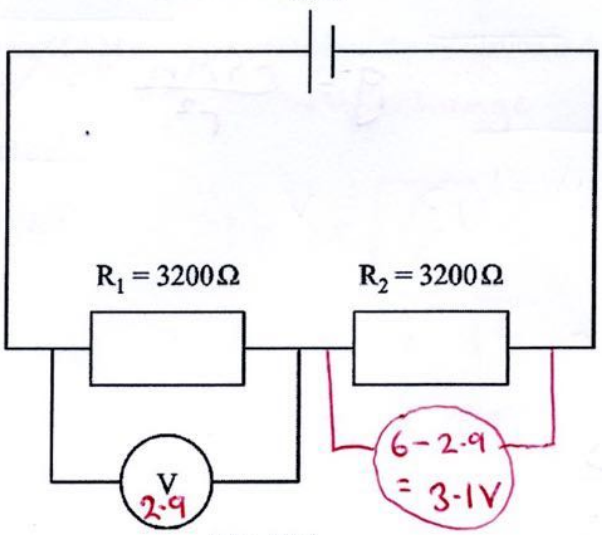


Fig. 31.1

The p.d. across R_1 is 2.9 V.

(a) Show that R_c, the combined resistance of R_1 and the voltmeter resistance R_v, is about 3000 Ω. Assume that the cell has zero internal resistance.

$I = V/R = 3.1/3200 = 9.69 \times 10^{-4}$ A

$R_{TOTAL} = V_{TOTAL}/I = 6/9.69 \times 10^{-4} = 6193.5\,\Omega$

$\therefore R_c = 6193.5 - 3200$
$= 2993.5\,\Omega$

OR

$\frac{3000}{6200} \times 6$

$= 2.90$V

[2]

(b) Calculate the resistance of the voltmeter, R_v.

$\frac{1}{R_v} + \frac{1}{3200} = \frac{1}{2994}$

$R_v = 1 / \left(1/2994 - 1/3200 \right) =$

resistance = 46400 **[2]**

OR 48 kΩ if 3000 Ω used

32 **Fig. 32.1** represents the internal structure of a metal alloy.

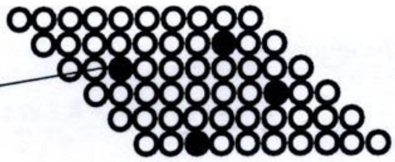


Fig. 32.1

Describe and explain how the presence of impurity atoms makes the metal harder.

Metals undergo plastic deformation as planes of atoms slip over one another and as dislocations move through the structure. Impurity atoms pin the dislocations & planes preventing slip. With reduced plastic deformation the metal is harder. **[3]**

33 Light of wavelength 633 nm passes through a diffraction grating.

The first order maximum is at an angle of 0.19 radian.

(a) Show that the grating has about 300 lines per mm.

$n\lambda = d \sin\theta$

$\therefore\ d = n\lambda / \sin\theta = 1 \times 633\times10^{-9} / \sin 0.19 = 3.35\times10^{-6}\,m$

Lines per mm $= 1\times10^{-3} / 3.35\times10^{-6} = 298$

[3]

(b) Calculate the number of orders of maximum that can be obtained from this grating with this light source.

$n = \dfrac{d\sin\theta}{\lambda}$ $\quad n_{max}$ is when $\sin\theta$ is closest to 1

$n = \dfrac{d}{\lambda} = \dfrac{3.35\times10^{-6}}{633\times10^{-9}} = 5.3$

[2]

so n_{max} must $= 5$

34 The half-life of a muon at rest is 1.52 μs. Muons in cosmic rays are observed to have half-lives of 10.4 μs.

Calculate the velocity of the muons in cosmic rays.

$\gamma = \frac{10.4}{1.52} = 6.842$

$\therefore 6.842 = \sqrt{1/_{1-v^2/c^2}}$ $\therefore \frac{1}{6.842^2} = 1 - \frac{v^2}{c^2}$

$\therefore \frac{v}{c} = \sqrt{1 - 1/_{6.842^2}}$ $\therefore v = c\sqrt{1 - 1/_{6.842^2}} =$

velocity = 2.97×10^8 m s^{-1} **[3]**

35 Theory suggests that about 14×10^9 years ago the Universe was much smaller than it is now and that the temperature of the Universe was about 3000 K. Since that time, the Universe has expanded and cooled to a background temperature of about 2.8 K.

(a) State the observation that suggests that the Universe is continuing to expand.

The Hubble relationship $V = H_0 d$ ← from supernova data

↑ from red-shifted spectra

[1]

(b) The energy of photons released in the very early Universe has reduced by a factor of about 1000. Calculate the factor by which the wavelength of the photons has changed during this time.

$E = \frac{hc}{\lambda}$ $\therefore$ 1000 × longer

[2]

36 Palladium-103 is a beta-emitter with a half-life of 17 days. For some cases of cancer, 'seeds' of palladium-103 are placed in the affected organ near the tumour and remain there: they are not removed.

(a) In a medical procedure, a cluster of cells is exposed to the beta radiation from palladium-103. The initial activity of the source is 1.8×10^5 Bq.

→ = J/kg ↗ 0.004 kg

Estimate the dose in gray received by a cluster of cells of mass 4.0 g after one hour. = 3600 s

average energy of beta particle released by palladium-103 = 3.4×10^{-15} J

$$\frac{1.8 \times 10^5 \times 3600 \times 3.4 \times 10^{-15}}{0.004} =$$

dose received = 5.51×10^{-4} Gy **[2]**

(b) Evaluate the benefits and risks to the patient of this type of treatment compared with using a radioactive source outside the body.

Benefit → Most β particles transfer their energy just to the tumour.
Risk → Surgical procedures carry a risk of infection.
[2]

SECTION C

Answer **all** the questions.

37 This question is about the energy required to vaporise water.

A student performs a simple experiment in which she measures the change in mass of water as a kettle boils. The lid has been removed from the kettle so that the water vapour can escape.

These are her results:

mass of kettle and water at $t = 0$ s:	2.40 kg
mass of kettle and water at $t = 120$ s:	2.30 kg
power of kettle:	2100 W

120s

She concluded that the energy required for one molecule to go into the vapour state is 7.5×10^{-20} J.

(a) Show how the student reached this value.

molar mass of water = 18 g mol^{-1}

Energy = $Pt = 2100 \times 120 = 2.52 \times 10^5$ J

Mass boiled = $2.4 - 2.3 = 0.1$ kg

$\therefore E_{VAP} = 2.52 \times 10^5 / 0.1 = 2.52 \times 10^6$ J kg^{-1}

1 mol = 18g $\therefore E_{VAP} = \frac{2.52 \times 10^6}{1000} \times 18 = 45360$ J mol^{-1}

$\therefore E_{VAP} = 45360 / 6.02 \times 10^{23} = 7.53 \times 10^{-20}$ J per molecule.

[3]

(b) Suggest and explain why her value of 7.5×10^{-20} J is larger than the expected value of 6.9×10^{-20} J.

Energy is lost to surroundings. Some vapour may condense and drip back into the kettle.

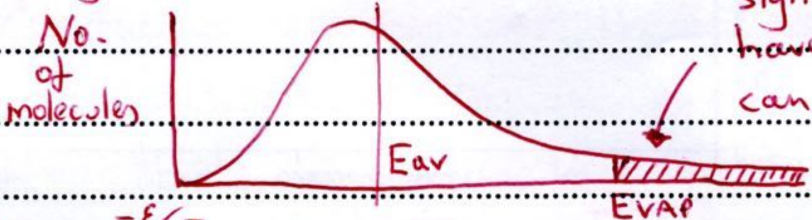
[2]

(c)* The average energy kT of a particle at 293 K (20 °C) is about 4×10^{-21} J. This is less than the energy required for one molecule to go into the vapour state. However, water does gradually evaporate at this temperature.

Use the idea of particle collisions and the Boltzmann factor to explain why some molecules escape the liquid at this temperature and why the rate of evaporation roughly doubles when the temperature of the liquid is raised from 293 K to 303 K.

k, the Boltzmann constant = 1.38×10^{-23} J K^{-1}

$kT = 4 \times 10^{-21}$ J is the average energy - due to random collisions between molecules energy is exchanged and a distribution of different energies is established.



$BF = e^{-E/kT}$

At 293 K $BF = e^{-6.9\times10^{-20}/1.38\times10^{-23}\times293} = 3.88\times10^{-8}$

At 303K $BF = e^{-6.9\times10^{-20}/1.38\times10^{-23}\times303} = 6.81\times10^{-8}$

$\frac{6.81}{3.88}$ = 1.76 × larger so ≈ 2× as many molecules can react per second. (i.e. have enough energy to)

[6]

38 This question is about the decay of protactinium.
Fig. 38.1 shows a graph of the natural log of corrected count rate A against time in seconds.

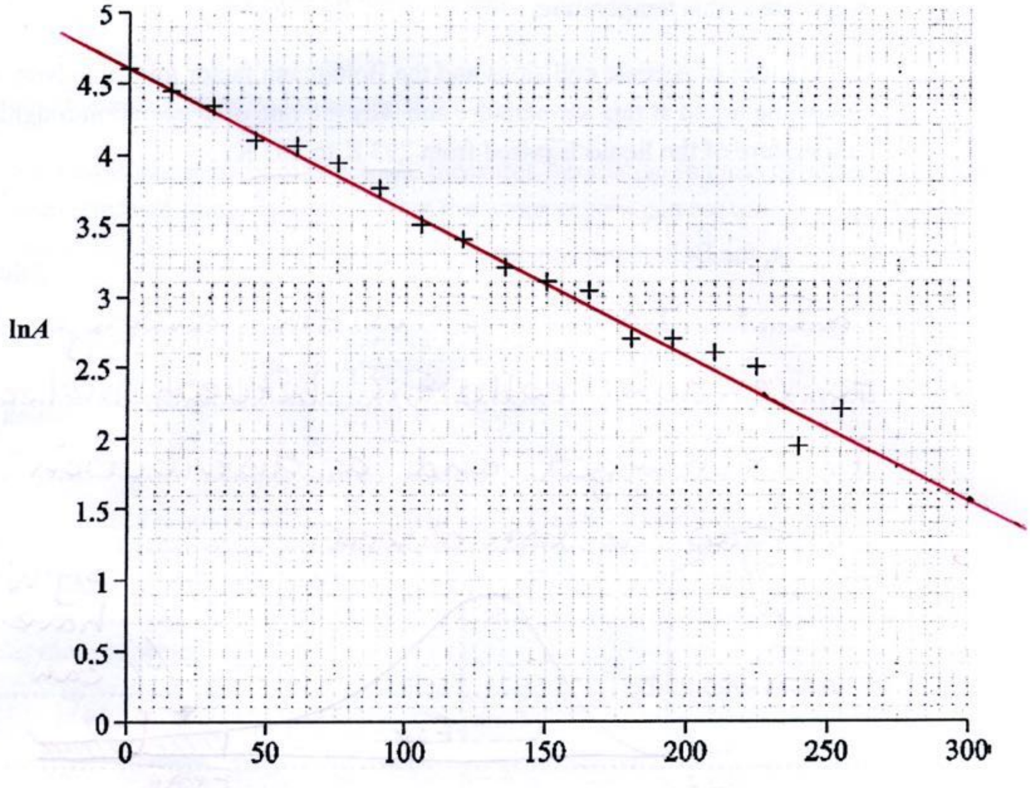


Fig. 38.1

(a) **(i)** Draw a best fit line on **Fig. 38.1**.

The equation of the line is $\ln A = \ln A_0 - \lambda t$ where λ is the decay constant and A_0 is the initial activity of the source.

Use this to show that the decay constant of the protactinium is about 0.01 s^{-1}.

$\ln A = \ln A_o - \lambda t$

$\lambda = \text{gradient} = \frac{4.6-1.5}{300} = 0.0103\ s^{-1}$

[3]

(ii) Use the value from **(a)(i)** to calculate the half-life of the source.

$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda} = \frac{\ln 2}{0.0103} =$

half-life of source = 67.1 s **[2]**

(b)* Here are two correct statements:

- Radioactive decay is a random process
- The decay curve of a radioisotope can be predicted mathematically.

Use your understanding of the decay constant to explain how both statements can be true for sources containing large numbers of atoms. Explain how you expect the scatter of the results shown in **Fig. 38.1** to change as the count rate falls.

λ, the decay constant is the probability that a nucleus will decay in unit time or, alternatively the proportion of nuclei that decay in unit time. Activity = $\lambda \times$ Number of Nuclei

This results in an exponential relationship as the rate of decay dN/dt is propational to the number of nuclei. $dN/dt = -\lambda N$ this gives $N = N_0 e^{-\lambda t}$ as a solution. For an individual nucleus λ is a probability which is consistent with random* nature of decay. For a large number of nuclei λ is a proportion or fraction that decay which is a clear mathmatical relationship that can be predicted.

* unpredictable **[6]**

39 This question is about the electron in the hydrogen atom. A simple model shown in **Fig. 39.1** pictures the electron as a standing wave in a box of length equal to the diameter of the atom. The electron can be bound to the proton if the total energy of the electron (kinetic energy + potential energy) is less than zero.

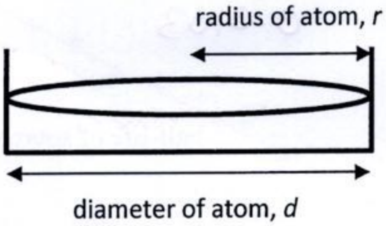


Fig. 39.1

(a) **(i)** Show that the kinetic energy of the electron in a box of diameter d is $\frac{h^2}{32mr^2}$.

$\lambda = h/p \therefore p = h/\lambda = h/4r$

$p = mv \therefore p^2 = m^2v^2 \therefore E_K = p^2/2m$

$\therefore E_K = \frac{(h/4r)^2}{2m} = \frac{h^2}{32mr^2}$

[3]

(ii) Calculate the kinetic energy of an electron trapped in a box of $r = 1 \times 10^{-10}$ m.

$E_K = (6.6 \times 10^{-34})^2 / 32 \times 9.1 \times 10^{-31} \times (1 \times 10^{-10})^2 =$

kinetic energy = 1.5×10^{-18} J **[2]**

(iii) Calculate the electrical potential energy of an electron at a distance of 1×10^{-10} m from a proton. Use this value and your answer from **(a)(ii)** to explain why an electron can be bound to a proton at this distance.

$k = 9.0 \times 10^{9}\ \text{N m}^2\ \text{C}^{-2}$

$$E_{elec} = \frac{-kQq}{r} = \frac{-9 \times 10^{9} \times (1.6 \times 10^{-19})^2}{1 \times 10^{-10}}$$

$$= -2.3 \times 10^{-18}\ \text{J}$$

$$E_{TOTAL} = E_K + E_{elec} = 1.5 \times 10^{-18} + -2.3 \times 10^{-18}$$

$$= -0.8 \times 10^{-18}\ \text{J}$$

Negative energy so electron is bound.

[4]

(b) In beta decay of a nucleus, a neutron decays into a proton and an electron.

Taking the radius of a nucleus to be about 10^{-14} m, explain, with supporting calculations, why the electron immediately leaves the nucleus.

$E_K = h^2/32mr^2$ as r is 10^4 × smaller E_K is 10^8 × larger = 1.5×10^{-10} J

$E_{elec} = -2.3 \times 10^{-18}$ J (per proton in nucleus) so now E_{TOTAL} is positive & electron is not bound ($E_T = E_{elec} + E_K = -2.3 \times 10^{-18} + 1.5 \times 10^{-10}$ $= 1.5 \times 10^{10}$ J)

[4]

40 This question is about energy from a nuclear power plant.

A power plant generator produces a voltage of 25 kV a.c. The electrical power output of such a plant is about 500 MW. A transformer of turns ratio 1:16 is used to step up the voltage for transmission along the high voltage cables.

(a) Calculate the current in the cables at the higher voltage.

$I_p = P/V = 500 \times 10^6 / 25 \times 10^3 = 20{,}000$ A

$I_s = 20000/16 =$

current = 1250 A **[2]**

The equation below shows one of many ways that uranium-235 can undergo fission.

$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + ^{1}_{0}n + ^{1}_{0}n + ^{1}_{0}n$

(b) **(i)** Explain how this process can form a chain reaction and why a minimum mass of uranium is required for the reaction to proceed.

The neutron from one fission event can set off another fission event that can then set off another to give a chain reaction. If mass of ^{235}U is too low then probability of neutron escaping mass is high so average chance of setting off another event is < 1. **[3]**

(ii) Here are the masses of the particles in the reaction:

neutron	=	1.0087 u
uranium-235	=	235.0439 u
barium-141	=	140.9144 u
krypton-92	=	91.9261 u

Calculate the energy released in one fission reaction:

u = 1.7 × 10^{-27} kg

mass at start/u: 1.0087 + 235.0439 = 236.0526

mass at end/u: 3 × 1.0087 + 140.9144 + 91.9261 = 235.8666

$\Delta m = -0.186$ u
$= 0.186 \times 1.7 \times 10^{-27}$
$= 3.162 \times 10^{-28}$ kg

$E = mc^2$
$= 3.162 \times 10^{-28} \times (3 \times 10^8)^2$
$=$

energy released = 2.85×10^{-11} J **[3]**

(c) Most working power plants use enriched uranium which contains about 3% uranium-235 which undergoes fission, and 97% uranium-238 which does not undergo fission. A promising alternative fuel to uranium-235 is uranium-233. This is produced from the plentiful isotope thorium-232 which is converted into thorium-233 by neutron bombardment followed by beta-decay.

Research into uranium-233 reactors was abandoned in the 1970s as uranium-235 plants produce plutonium-239, which was needed for nuclear weapons. Research has recently resumed into obtaining fuel from thorium-232.

Here are some data about a proposed uranium-233 power plant:

energy released per reaction = 200 MeV

mean power generated by fission reactions = 1400 MW

mass of thorium-232 atom = mass of uranium-233 atom = 4×10^{-25} kg (1 significant figure)

Use this data to calculate an estimate of the total mass of thorium-232 used in one year, and suggest one reason why research into nuclear fuel obtained from thorium has started again after being abandoned for 40 years.

1 year = 3.2×10^7 s

1 eV = 1.6×10^{-19} J

200 MeV = $200 \times 10^6 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-11}$ J

$E = Pt = 1400 \times 10^6 \times 3.2 \times 10^7 = 4.48 \times 10^{16}$ J/yr

No of Th atoms needed = $4.48 \times 10^{16} / 3.2 \times 10^{-11} = 1.4 \times 10^{27}$

Mass of Th = $1.4 \times 10^{27} \times 4 \times 10^{-25}$ = 560 kg

As ^{235}U is a low abundance isotope and Pu is now not required research into Th fission is a good idea.

mass used per year = 600 1s.f. kg **[4]**

41 This question is about sampling sounds. **Fig. 41.1** shows part of a waveform. This waveform has been sampled at the points shown by small circles.

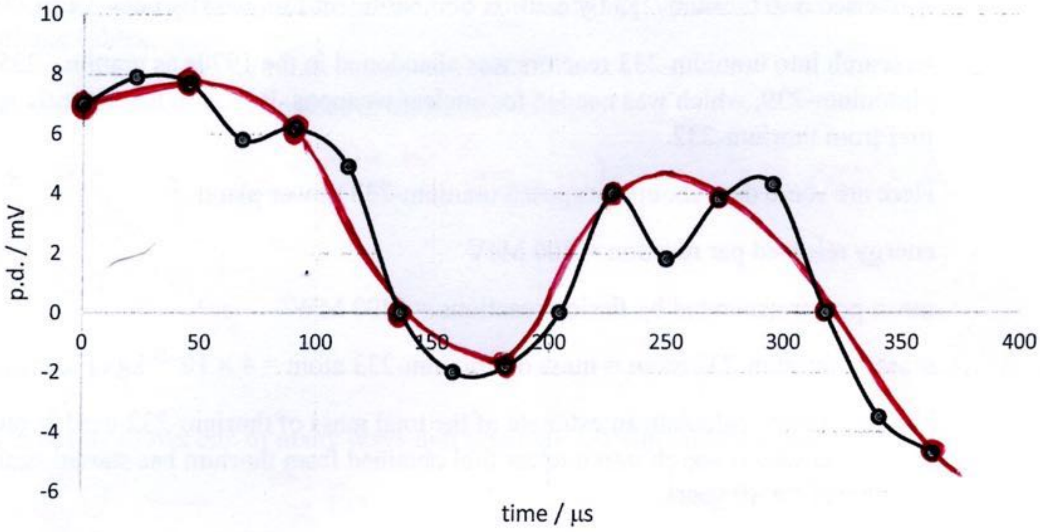


Fig.41.1

The sampling rate is 44 kHz.

(a) On **Fig. 41.1** sketch the waveform that would be reproduced if the sample rate is reduced to 22 kHz. Explain your reasoning and state how the reproduced waveform will differ from the original waveform.

Every other sample is ignored. The waveform will lose high frequency components and aliases may be generated.

[3]

(b) A student estimates that the system uses 50 000 voltage levels. Calculate how many bits are required to produce this number of levels and suggest a more likely value for the number of voltage levels.

$\log_2 50{,}000 = 15.6$ so 16 bit required

More likely number is $2^{16} = 65536$ levels.

[3]

(c) This system is used for high quality sound. Explain why it is necessary to sample at a frequency of 44 kHz when the highest note that can be heard is about 20 000 Hz.

Sampling frequency must be > 2x highest signal frequency to encode the high frequency components and avoid aliases.

[2]

(d) Telephone systems are often designed to use 8 bit sampling at 8 kHz instead of the 16 bit sampling at 44 kHz used for music. Suggest and explain why this decision was made in designing those systems and explain why recorded music can sound distorted on a telephone.

8 bit 8kHz is 64 kbs^{-1} and 16 bit 44kHz is 704 kbs^{-1} which is 11x greater. As telephones are just speech and speech is understandable at 64 kbs^{-1} this was chosen as you can fit 11x more calls on the same line.

[3]

END OF QUESTION PAPER