Please check the examination details below before entering your candidate information

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**Pearson Edexcel Level 3 GCE**

| Centre Number | Candidate Number |
|---|---|
| | |

# Monday 20 May 2019

| Afternoon (Time: 1 hour 45 minutes) | Paper Reference **9PH0/01** |
|---|---|

# Physics

## Advanced

## Paper 1: Advanced Physics I

**You do not need any other materials.**

Total Marks

## Instructions

- Use **black** ink or ball-point pen.
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided
  – *there may be more space than you need.*

## Information

- The total mark for this paper is 90.
- The marks for **each** question are shown in brackets
  – *use this as a guide as to how much time to spend on each question.*
- You may use a scientific calculator.
- In questions marked with an **asterisk** (*), marks will be awarded for your ability to structure your answer logically showing how the points that you make are related or follow on from each other where appropriate.

## Advice

- Read each question carefully before you start to answer it.
- Try to answer every question.
- Check your answers if you have time at the end.
- You are advised to show your working in calculations including units where appropriate.

*Turn over* ▶

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**Answer ALL questions.**

**All multiple choice questions must be answered with a cross ☒ in the box for the correct answer from A to D. If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.**

**1** Which of the following particles is an example of a fundamental particle?

☐ **A** nucleus

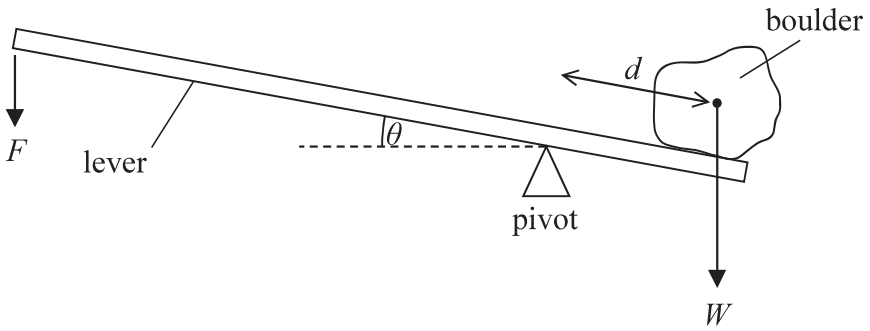
☒ **B** neutrino

☐ **C** pion

☐ **D** proton

**(Total for Question 1 = 1 mark)**

**2** A person uses a pivoted lever to lift a boulder of weight $W$ as shown.




The centre of gravity of the boulder is a distance $d$ from the pivot. The angle of the lever to the horizontal is $\theta$.

Which expression is equal to the moment of $W$ about the pivot?

☐ **A** $Wd$

☒ **B** $Wd\cos\theta$

☐ **C** $Wd\sin\theta$

☐ **D** $Wd\tan\theta$

**(Total for Question 2 = 1 mark)**

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**3** A space rocket lifts off vertically.



The rocket lifts off because

☒ **A** the exhaust gases exert a force on the ground.

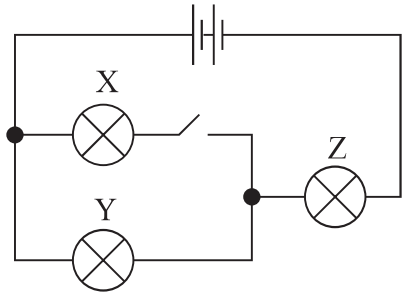
☒ **B** the exhaust gases exert a force on the rocket.

☒ **C** the ground exerts a force on the rocket.

☒ **D** the rocket exerts a force on the ground.

**(Total for Question 3 = 1 mark)**

**4** A circuit consists of three identical 1.5 V bulbs connected to two 1.5 V cells.



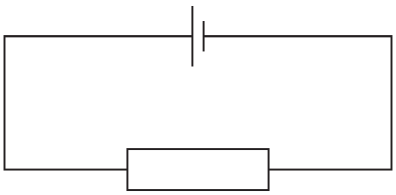

The switch is closed.
Which row describes the change in brightness of bulb Y and bulb Z?

| | Y | Z |
|---|---|---|
| ☒ **A** | brighter | brighter |
| ☒ **B** | brighter | dimmer |
| ☒ **C** | dimmer | brighter |
| ☒ **D** | dimmer | dimmer |

**(Total for Question 4 = 1 mark)**

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**5** A cell of e.m.f. 1.5 V is connected to a 5.0 Ω resistor. The terminal potential difference across the cell is 1.0 V.

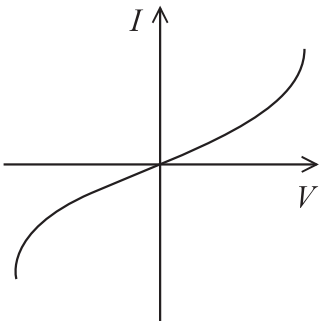


Which of the following is the current in the circuit?

- ☒ **A** 0.1 A
- ☒ **B** 0.2 A
- ☒ **C** 0.3 A
- ☒ **D** 0.5 A

**(Total for Question 5 = 1 mark)**

**6** The diagram shows a graph of current $I$ against potential difference $V$ for an electrical component.




Which of the following components would produce a graph of this shape?

- ☒ **A** filament bulb
- ☒ **B** metallic conductor
- ☒ **C** negative temperature coefficient thermistor
- ☒ **D** ohmic conductor

**(Total for Question 6 = 1 mark)**

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**7** The force between two identical point charges, X and Y, is $F$.

Charge X is doubled; charge Y remains the same.

Which row of the table gives the force on each charge?

| | X | Y |
|---|---|---|
| ☒ **A** | $F$ | $F$ |
| ☒ **B** | $F$ | $2F$ |
| ☒ **C** | $2F$ | $F$ |
| ☒ **D** | $2F$ | $2F$ |

**(Total for Question 7 = 1 mark)**

**8** A capacitor of capacitance $C$ is discharged through a resistor of resistance $R$.
The initial discharge current is $I_0$.

Which of the following expressions gives the current after a time equal to $RC$?

☒ **A** $\frac{I_0}{e}$

☒ **B** $\frac{I_0}{2}$

☒ **C** $I_0 e^{-RC}$

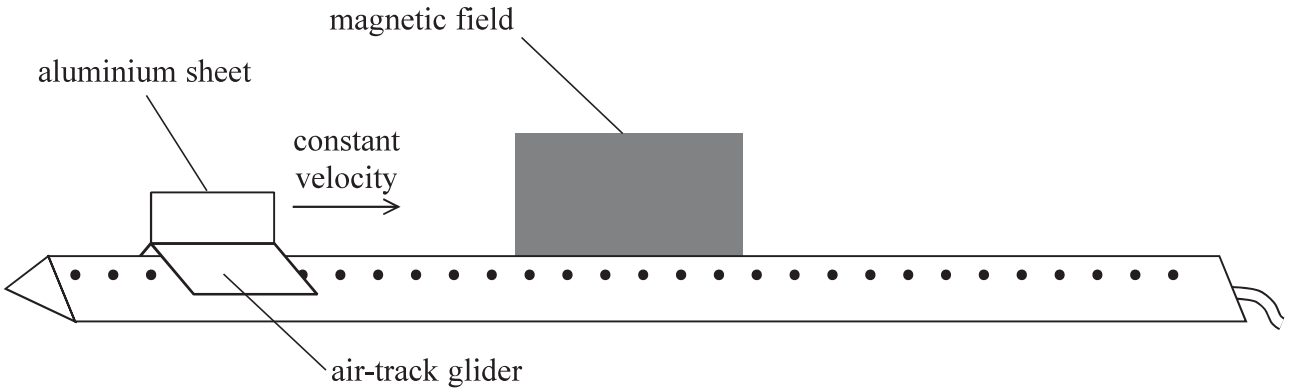
☒ **D** $I_0 \ln \frac{1}{e}$

**(Total for Question 8 = 1 mark)**

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**9** A rectangular sheet of aluminium is attached to an air-track glider as shown.

The glider moves towards a region of uniform magnetic field at a constant velocity. When the glider enters the magnetic field, the magnetic flux is perpendicular to the aluminium sheet.




Which row of the table describes the velocity of the glider as it enters the magnetic field, when it is completely within the magnetic field and as it leaves the magnetic field?

| | Enters the magnetic field | Within the magnetic field | Leaves the magnetic field |
|---|---|---|---|
| ☒ **A** | constant | decreasing | constant |
| ☒ **B** | decreasing | constant | increasing |
| ☒ **C** | decreasing | constant | decreasing |
| ☒ **D** | decreasing | decreasing | decreasing |

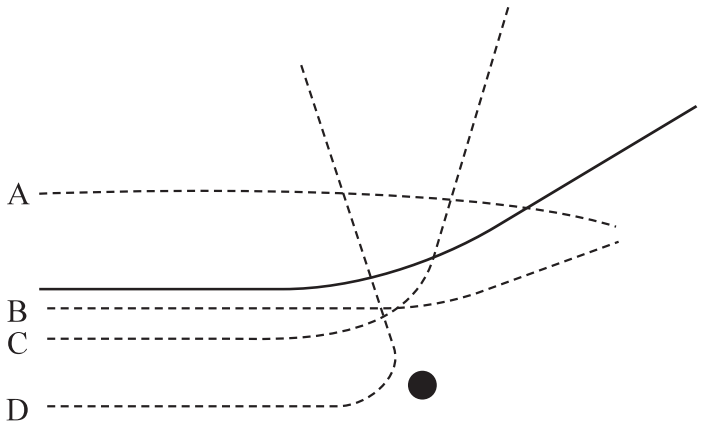
**(Total for Question 9 = 1 mark)**

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**10** The solid line shows the path of an alpha particle as it passes close to a nucleus.




Another alpha particle approaches the nucleus with the same initial kinetic energy.

Which dashed path is possible for this alpha particle?

☒ **A**

☒ **B**

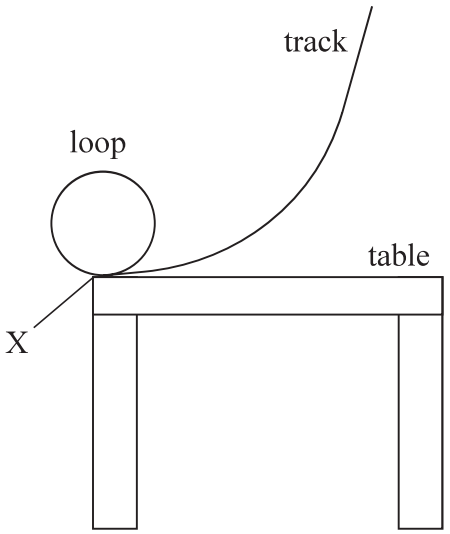
☒ **C**

☒ **D**

**(Total for Question 10 = 1 mark)**

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**11** A track for toy cars can be built with a circular loop as shown.




A toy car is placed on the track at various heights. It travels around the loop before leaving the track horizontally at X.

(a) The loop has radius $r$ and the mass of the toy car is $m$. It is possible for a toy car to complete the loop without losing contact with the inside of the track.

For this to occur the minimum speed of the toy car at the top of the loop $v_{top}$ is given by

$$v_{top} = \sqrt{gr}$$

Explain why.

**(2)**

At the top of the loop the resultant (centripetal) force is $F = mv^2/r$, provided by the weight and the reaction force from the track.

At the minimum speed the reaction force is zero, so $F = mg$ only: $mg = mv^2/r$, so $v_{top} = \sqrt{(gr)}$.

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(b) The toy car just completes the loop without losing contact with the track.

Show that the speed of the toy car at the bottom of the loop is about 3 m s$^{-1}$.

$r = 0.15$ m

**(3)**

Energy is conserved: KE at bottom = KE at top + GPE gained ($h = 2r = 0.30$ m)

$\frac{1}{2}mv_{bottom}^2 = \frac{1}{2}mv_{top}^2 + mgh$, and $v_{top}^2 = gr$, so $m$ cancels:

$v_{bottom}^2 = gr + 2gh = 9.81 \times 0.15 + 2 \times 9.81 \times 0.30 = 7.36$ m$^2$ s$^{-2}$

$v_{bottom} = \sqrt{7.36} = 2.7$ m s$^{-1}$, which is about 3 m s$^{-1}$

(c) The toy car leaves the track at X with a horizontal velocity of 3.0 m s$^{-1}$.

X is 0.65 m above the floor.

Calculate the horizontal displacement of the car from X when it hits the floor.

**(4)**

Vertically: $u = 0$, $s = 0.65$ m, $a = 9.81$ m s$^{-2}$

$s = ut + \frac{1}{2}at^2$, so $0.65$ m $= \frac{1}{2} \times 9.81$ m s$^{-2} \times t^2$

$t = \sqrt{(2 \times 0.65 \div 9.81)} = 0.364$ s

Horizontally (constant velocity): $s = vt = 3.0$ m s$^{-1} \times 0.364$ s $= 1.09$ m

Horizontal displacement = 1.1 m

**(Total for Question 11 = 9 marks)**

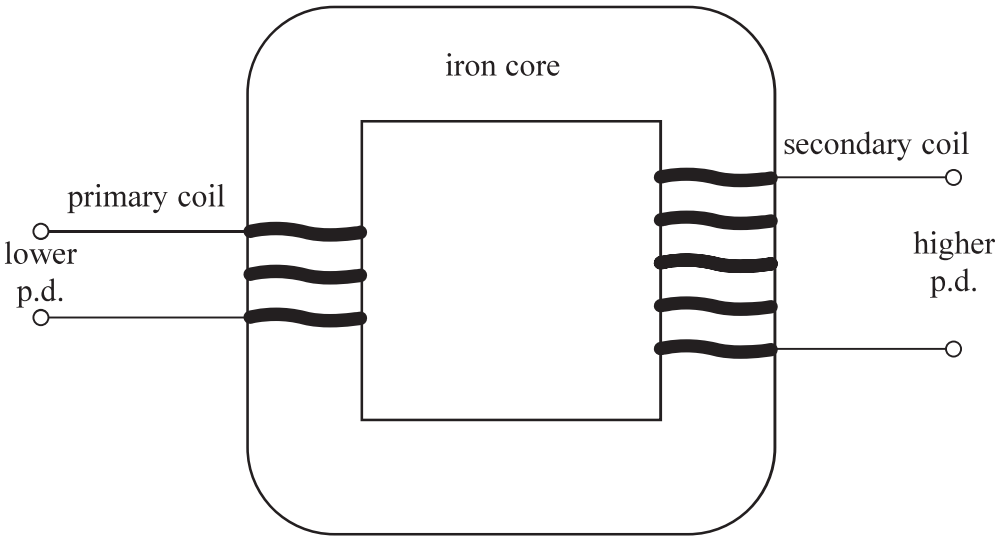
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**12** Electrical transmission systems are used to transmit electrical power from place to place. Transformers are used to change potential differences (p.d.) and power transmission cables are used to transmit power.

(a) The diagram shows a step-up transformer.




A step-up transformer is used to convert a lower p.d. to a higher p.d. An alternating p.d. is applied to the primary coil.

Explain how a higher p.d. is produced across the secondary coil.

**(4)**

The alternating current in the primary coil produces a changing (alternating) magnetic flux in the iron core.

The iron core links this changing magnetic flux to the secondary coil.

The changing magnetic flux (linkage) induces an emf in the secondary coil (Faraday's law).

The secondary coil has more turns than the primary, so the rate of change of flux linkage is greater and a larger emf is induced: $V_s/V_p = N_s/N_p$.

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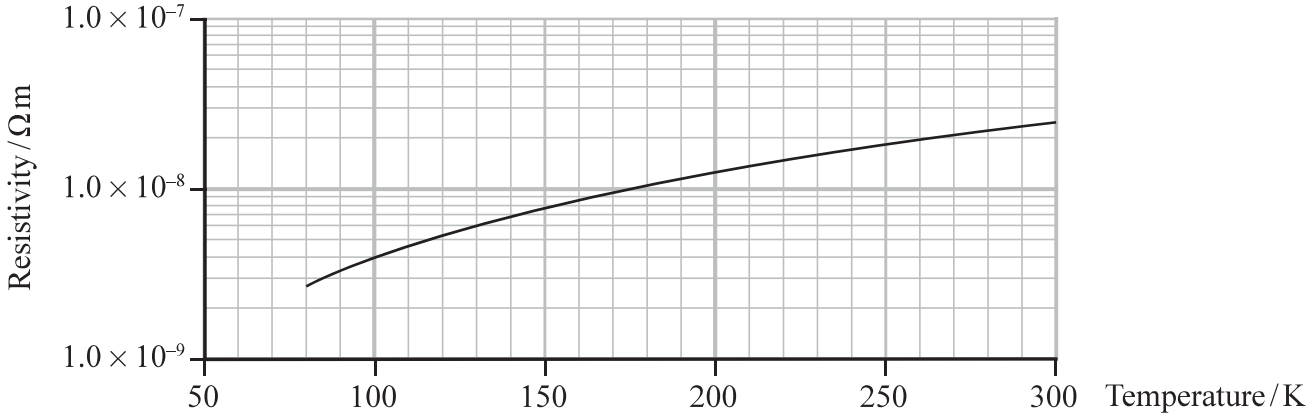


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(b) Efficient electrical transmission systems are being developed using superconductors. Superconductors have zero resistance at low temperatures, and therefore no power is wasted by transfer to thermal energy unlike copper cable systems.

In one project a 1.05 km length of copper cable at a temperature of 270 K has been replaced by a superconductor. The superconductor has a cooling system which requires power.

The graph shows the variation of resistivity with temperature for copper.




Deduce whether the power requirement of the superconductor cooling system is less than the power losses in the copper cable.

transmission power = 40 MW

transmission potential difference = 110 kV

cross-sectional area of copper cable = 145 mm$^2$

power requirement of cooling system for the superconductor = 7 kW

**(5)**

From the graph, at 270 K the resistivity of copper $\rho = 2.0 \times 10^{-8}\ \Omega\ m$

$R = \rho l/A = 2.0 \times 10^{-8}\ \Omega\ m \times 1050\ m \div 145 \times 10^{-6}\ m^2 = 0.145\ \Omega$

$P = VI$, so $I = P/V = 40 \times 10^6\ W \div 110 \times 10^3\ V = 364\ A$

Power lost in the copper cable: $P = I^2R = (364\ A)^2 \times 0.145\ \Omega$

$P = 1.92 \times 10^4\ W = 19\ kW$

The power losses in the copper cable (19 kW) are more than the 7 kW needed for the cooling system, so the power requirement of the cooling system is less and the superconductor saves energy.

**(Total for Question 12 = 9 marks)**




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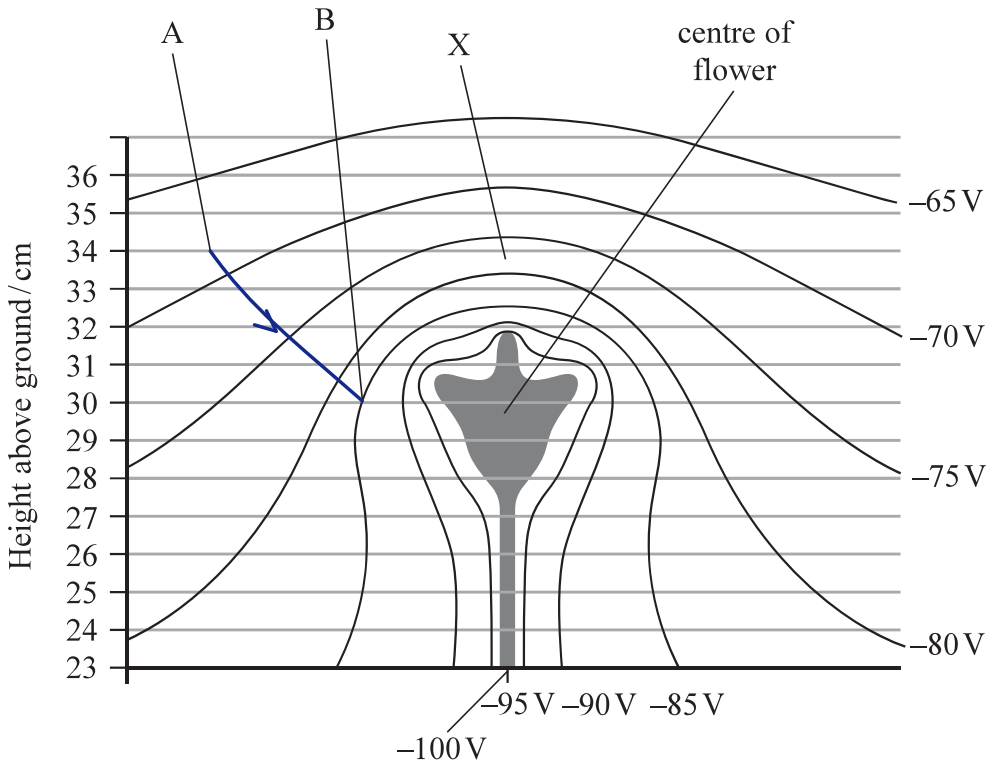
**13** Some flowers are negatively charged and surrounded by an electric field. This helps to attract bees.

(a) State what is meant by an electric field.

**(1)**

A region where a charged particle experiences a force.

(b) The diagram shows lines of equipotential surrounding a flower.




(i) Determine the electric field strength at X.

**(3)**

At X: between the −75 V and −80 V equipotentials, so $\Delta V = 5$ V

Distance between these lines at X: $\Delta d = 0.9$ cm $= 0.009$ m

$E = \Delta V / \Delta d = 5 \text{ V} \div 0.009 \text{ m} = 556 \text{ V m}^{-1}$

Electric field strength at X = $560 \text{ V m}^{-1}$

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(ii) Draw the electric field line between point A and point B on the diagram.

**(2)**

(iii) An equation for electric potential $V$ is

$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

This applies to a radial field.

Deduce whether the electric field in the region directly above the flower is radial. You should take values from the diagram. A graphical method is not required.

**(3)**

For a radial field $V = Q/4\pi\varepsilon_0 r$, so $V \times r$ would be constant.

Taking r from the centre of the flower (height 29.7 cm), directly above it:

V = −80 V at r = 3.7 cm: Vr = −296 V cm

V = −75 V at r = 4.6 cm: Vr = −345 V cm

V = −70 V at r = 6.0 cm: Vr = −420 V cm

Vr is not constant, so the field above the flower is not radial.

(c) A bee has short hairs which are thought to carry charge.

State how the bee might use this to detect the electric field of a flower.

**(1)**

The charged hairs experience a force (are attracted or repelled) in the field, so they move.

(d) When the bee is collecting nectar from the plant, the electric field strength decreases. It is thought that this warns other bees that the nectar supply is low.

State the effect of a decreased electric field strength on the equipotential lines.

**(1)**

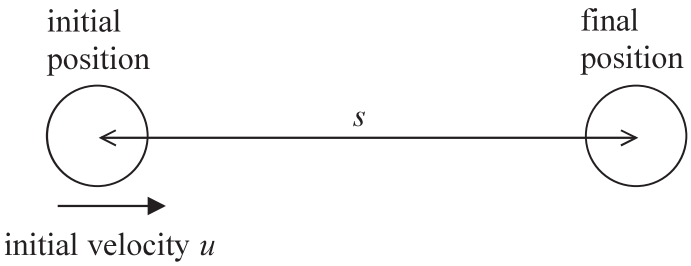
The equipotential lines would be further apart.

**(Total for Question 13 = 11 marks)**

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**14** A student carried out an experiment with coins.

(a) She gave a 2p coin a sharp tap, so that it slid along a horizontal surface and came to rest as shown.




view from above

The student recorded the distance $s$ moved by the coin.

She then replaced the 2p coin with a 1p coin and repeated the process.

The student read that the frictional force between an object and a surface is directly proportional to the mass of the object. She suggested that, in her experiment, $u$ is directly proportional to $\sqrt{s}$ and is independent of the mass of the coin.

Discuss the validity of this suggestion.

**(6)**

Using $v^2 = u^2 + 2as$ with final velocity $v = 0$: $u^2 = -2as$, so $u = \sqrt{(-2as)}$, where $a$ is negative (a deceleration).

The deceleration $a$ is caused by the frictional force $F$ between the coin and the surface.

Newton's second law: $F = ma$, where $F$ is the frictional force.

The friction is proportional to the mass, $F = km$, so $km = ma$ and $a = k$: the mass cancels, so $a$ is constant for a given surface.

So the deceleration of the 1p coin is the same as for the 2p coin, and $u = \sqrt{(2ks)}$, so $u \propto \sqrt{s}$ with the same constant for both coins.

Therefore the suggestion is valid: $u$ is directly proportional to $\sqrt{s}$ and is independent of the mass of the coin (the same as using work done by friction $Fs = \frac{1}{2}mu^2$ with $F = km$, where $m$ cancels).

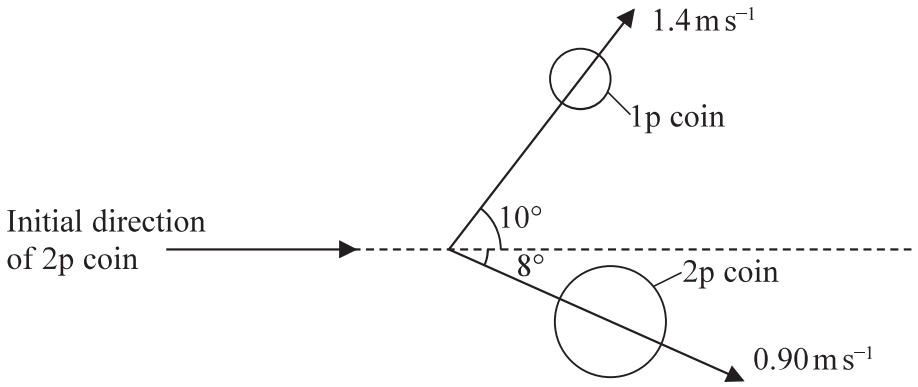
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(b) She arranged a collision between a 2p coin and a stationary 1p coin. She noted the directions in which the coins moved after the collision and determined their velocities.




(i) Show that the velocity of the 2p coin just before the collision was about 2 m s$^{-1}$.

mass of 2p coin = 7.1 g

mass of 1p coin = 3.6 g

**(4)**

Momentum $p = mv$; momentum is conserved in the initial (x) direction:

$7.1\ g \times u = 7.1\ g \times 0.90\ m\ s^{-1} \times \cos 8° + 3.6\ g \times 1.4\ m\ s^{-1} \times \cos 10°$

$7.1u = 6.33 + 4.96 = 11.29$

$u = 11.29 \div 7.1 = 1.59\ m\ s^{-1}$, which is about $2\ m\ s^{-1}$

(ii) Show that the collision was inelastic.

**(2)**

Initial $E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 7.1 \times 10^{-3}\ kg \times (1.59\ m\ s^{-1})^2 = 9.0 \times 10^{-3}\ J$

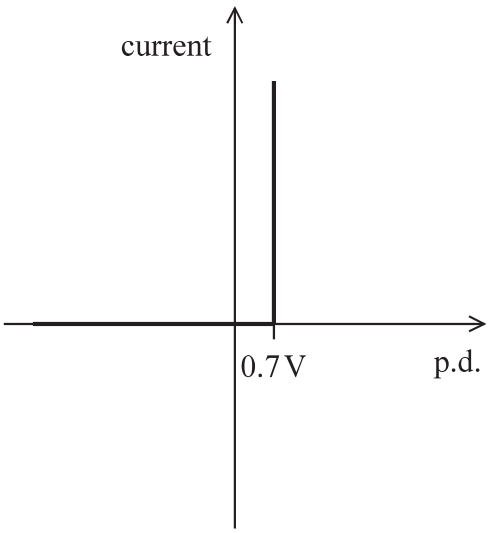
Final $E_k = \frac{1}{2} \times 7.1 \times 10^{-3} \times 0.90^2 + \frac{1}{2} \times 3.6 \times 10^{-3} \times 1.4^2 = 6.4 \times 10^{-3}\ J$

The kinetic energy after the collision is less than before, so kinetic energy is not conserved and the collision is inelastic.

**(Total for Question 14 = 12 marks)**

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**15** The graph shows how current varies with potential difference (p.d.) for an ideal diode.




(a) Describe how the current through this diode varies for positive p.d.s and negative p.d.s.

**(2)**

*The diode only conducts (current flows) when the potential difference across it is at least +0.7 V; above 0.7 V the current can be any value.*

*When the p.d. is negative (reversed), and below 0.7 V, the diode does not conduct, so the current is zero.*

(b) An alternating p.d. $V_{IN}$ has a peak value of 3.4 V.

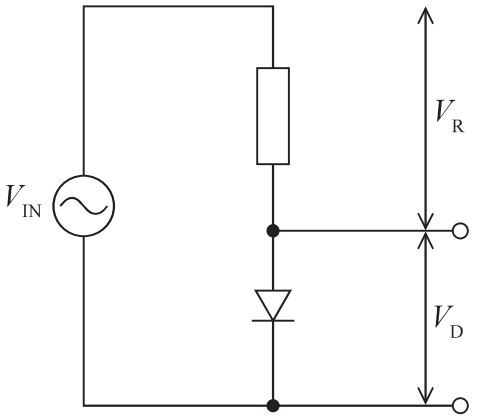
(i) Calculate the r.m.s. value.

**(2)**

$V_{rms} = V_0/\sqrt{2} = 3.4\ V \div \sqrt{2} = 2.40\ V$

r.m.s. value = *2.4 V*

(ii) $V_{IN}$ is applied to a diode and resistor as shown.




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The p.d. across the resistor is $V_R$ and the p.d. across the diode is $V_D$. $V_D$ is the output.

Explain why $V_{IN} = V_R + V_D$ at any given time.

**(2)**

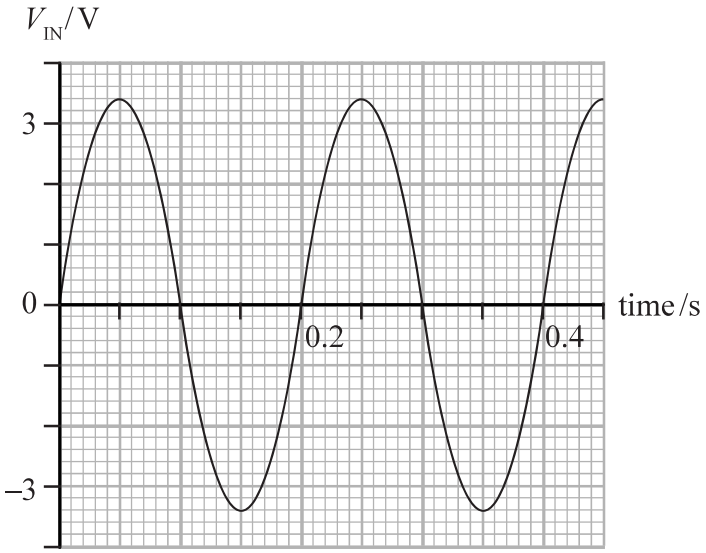
*Energy is conserved (Kirchhoff's second law); p.d. is energy per unit charge.*

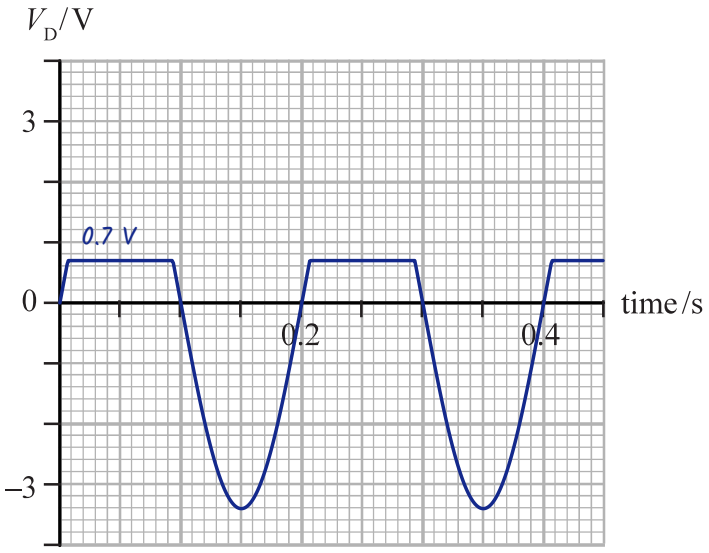
*So in this series circuit the sum of the p.d.s across the resistor and diode must equal the e.m.f. applied, $V_{IN}$.*

(iii) The graph shows how $V_{IN}$ varies with time.

Sketch a graph of $V_D$ against time using the axes provided below.

**(3)**




**(Total for Question 15 = 9 marks)**

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**16** A muon (μ) is a lepton with a mass of 106 MeV/$c^2$.

(a) Calculate the mass of a muon in kg.

**(3)**

$E = 106 \times 10^6$ eV $\times 1.60 \times 10^{-19}$ J eV$^{-1}$ $= 1.70 \times 10^{-11}$ J

$m = E/c^2 = 1.70 \times 10^{-11}$ J $\div (3.00 \times 10^8$ m s$^{-1})^2$

$m = 1.88 \times 10^{-28}$ kg

Mass of muon = $1.9 \times 10^{-28}$ kg

(b) Muons are produced from the decay of pions in the upper atmosphere.

An example of this decay is given by the equation

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

(i) Explain how this decay obeys the laws of conservation of charge, baryon number and lepton number.

**(3)**

Charge: $-1 = -1 + 0$, so charge is conserved.

Baryon number: $0 = 0 + 0$ (none of the particles are baryons), so baryon number is conserved.

Lepton number: $0 = +1 + (-1)$, so lepton number is conserved.

(ii) The masses of these three particles, in MeV/$c^2$, are given below.

| $\pi^-$ | $\mu^-$ | $\bar{\nu}_\mu$ |
|---|---|---|
| 140 | 106 | ≈0 |

Explain why the total kinetic energy of the products of this decay is approximately 34 MeV. Assume the $\pi^-$ is stationary.

**(2)**

Mass difference = $140 - (106 + 0) = 34$ MeV/$c^2$; this mass is converted to kinetic energy.

$E = mc^2 = 34$ (MeV/$c^2$) $\times c^2 = 34$ MeV, the total kinetic energy of the products.

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(iii) State which two conservation laws could be used to calculate the kinetic energy of the $\mu^-$ and the $\bar{\nu}_\mu$ just after the decay of the $\pi^-$.

**(2)**

Conservation of mass-energy and conservation of momentum.

*(iv) The muons are produced at a height of 10 km in the atmosphere. The velocity of the muons is $0.99c$. The average lifetime for muons is normally 2.2 μs and yet muons produced in the upper atmosphere are found in significant numbers at sea level.

Discuss this apparent anomaly.

**(6)**

Time to reach sea level: $t = d/v = 10\ 000\ m \div (0.99 \times 3.00 \times 10^8\ m\ s^{-1})$

$t = 3.4 \times 10^{-5}\ s = 34\ \mu s$

This is about 15 times longer than the 2.2 μs lifetime (in 2.2 μs a muon travels only 653 m, much less than 10 km), so classically almost all would decay before sea level.

But the muons travel at a relativistic speed (0.99c, close to the speed of light), so relativistic effects apply: time dilation.

Measured in the Earth's frame, time passes more slowly for the moving muon, so the time between events (the muon lifetime) is much longer.

$\gamma = 1/\sqrt{(1 - 0.99^2)} = 7.1$, so the muon lifetime increases to $7.1 \times 2.2\ \mu s = 16\ \mu s$.

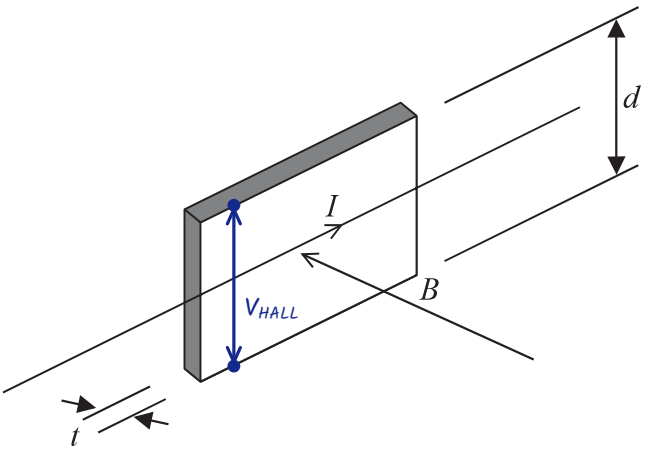
So many muons survive the journey and significant numbers are found at sea level.

**(Total for Question 16 = 16 marks)**

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**17** Tiny sensors in smartphones could be used to determine the position of the phone on the Earth's surface by measuring the Earth's magnetic flux density.

A current $I$ and a magnetic field of flux density $B$ are applied to a slice of semiconductor as shown. The slice has thickness $t$ and depth $d$.




Electrons collect at the top edge of the slice and the bottom edge becomes positively charged. As a result a potential difference known as a Hall voltage $V_{HALL}$ develops.

(a) Explain why electrons will collect at the top edge of the slice.

**(2)**

The current (moving electrons) is perpendicular to the magnetic field, so there is a force on the electrons.

By Fleming's left hand rule (electrons move opposite to I), the force on the electrons is upwards.

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(b) Add to the diagram to show clearly two points between which $V_{HALL}$ develops.

**(1)**

(c) Electrons continue to collect at the top edge of the slice, until the force on a moving electron due to the magnetic field is equal to the force on the electron due to the electric field.

Derive the following equation for $V_{HALL}$:

$$V_{HALL} = \frac{BI}{nte}$$

where $n$ is the number of charge carriers per unit volume of the semiconductor.

**(4)**

In equilibrium the magnetic force equals the electric force: $Bev = eE$

$E = V_{HALL}/d$, so $Bev = eV_{HALL}/d$

$I = nAve$, so $v = I/neA$: $B \times e \times I/(neA) = eV_{HALL}/d$, so $BI/(neA) = V_{HALL}/d$

$A = d \times t$, so $BI/(ned\ t) = V_{HALL}/d$

Cancelling $d$: $V_{HALL} = BI/nte$

(d) Show that the units are the same on each side of the equation

$$V_{HALL} = \frac{BI}{nte}$$

**(3)**

Left side: $V = J\ C^{-1} = N\ m\ C^{-1}$

$B$: from $F = BIl$, $T = N\ A^{-1}\ m^{-1}$; $I$ in A; $n$ in $m^{-3}$; $t$ in m; $e$ in C

Right side: $BI/nte = (N\ A^{-1}\ m^{-1} \times A) \div (m^{-3} \times m \times C)$

$= N\ m^{-1} \div (m^{-2}\ C) = N\ m\ C^{-1}$, the same as the left side.

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(e) The table gives the values of $n$ and $t$ for a number of material samples.

| material | $n$ / m$^{-3}$ | $t$ / m |
|---|---|---|
| copper | $8.47 \times 10^{28}$ | $110 \times 10^{-6}$ |
| germanium | $2.25 \times 10^{19}$ | $1.10 \times 10^{-6}$ |
| silicon | $1.44 \times 10^{16}$ | $120 \times 10^{-6}$ |

Deduce which sample would result in the largest Hall voltage for a particular current and magnetic field.

**(2)**

$V_{HALL} = BI/nte$, so with the same B and I, $V_{HALL} \propto 1/nt$

nt: copper = $8.47 \times 10^{28} \times 110 \times 10^{-6} = 9.3 \times 10^{24}$ $m^{-2}$; germanium = $2.5 \times 10^{13}$ $m^{-2}$; silicon = $1.44 \times 10^{16} \times 120 \times 10^{-6} = 1.7 \times 10^{12}$ $m^{-2}$

Silicon has the smallest nt, so silicon gives the largest Hall voltage.

(f) Two sensors in the smartphone were used to determine the horizontal component $B_H$ and the vertical component $B_V$ of the Earth's magnetic flux density.

Calculate the angle of the Earth's magnetic field to the horizontal.

$B_H = 19.0\,\mu T$

$B_V = 49.0\,\mu T$

**(2)**

$\tan \theta = B_V/B_H = 49.0\ \mu T \div 19.0\ \mu T = 2.58$

$\theta = \tan^{-1} 2.58 = 68.8°$

Angle = 69°

**(Total for Question 17 = 14 marks)**

**TOTAL FOR PAPER = 90 MARKS**

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## List of data, formulae and relationships

| | | |
|---|---|---|
| Acceleration of free fall | $g = 9.81\ \text{m s}^{-2}$ | (close to Earth's surface) |
| Boltzmann constant | $k = 1.38 \times 10^{-23}\ \text{J K}^{-1}$ | |
| Coulomb law constant | $k = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}\ \text{N m}^2\ \text{C}^{-2}$ | |
| Electron charge | $e = -1.60 \times 10^{-19}\ \text{C}$ | |
| Electron mass | $m_e = 9.11 \times 10^{-31}\ \text{kg}$ | |
| Electronvolt | $1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$ | |
| Gravitational constant | $G = 6.67 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$ | |
| Gravitational field strength | $g = 9.81\ \text{N kg}^{-1}$ | (close to Earth's surface) |
| Permittivity of free space | $\varepsilon_0 = 8.85 \times 10^{-12}\ \text{F m}^{-1}$ | |
| Planck constant | $h = 6.63 \times 10^{-34}\ \text{J s}$ | |
| Proton mass | $m_p = 1.67 \times 10^{-27}\ \text{kg}$ | |
| Speed of light in a vacuum | $c = 3.00 \times 10^{8}\ \text{m s}^{-1}$ | |
| Stefan-Boltzmann constant | $\sigma = 5.67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4}$ | |
| Unified atomic mass unit | $u = 1.66 \times 10^{-27}\ \text{kg}$ | |

### Mechanics

Kinematic equations of motion

$$s = \frac{(u + v)t}{2}$$

$$v = u + at$$

$$s = ut + \frac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

Forces

$$\Sigma F = ma$$

$$g = \frac{F}{m}$$

$$W = mg$$

moment of force $= Fx$

Momentum

$$p = mv$$

Work, energy and power

$$\Delta W = F\Delta s$$

$$E_k = \frac{1}{2}mv^2$$

$$\Delta E_{grav} = mg\Delta h$$

$$P = \frac{E}{t}$$

$$P = \frac{W}{t}$$

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$$

$$\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}}$$

## Electric circuits

Potential difference

$$V = \frac{W}{Q}$$

Resistance

$$R = \frac{V}{I}$$

Electrical power and energy

$$P = VI$$

$$P = I^2R$$

$$P = \frac{V^2}{R}$$

$$W = VIt$$

Resistivity

$$R = \frac{\rho l}{A}$$

Current

$$I = \frac{\Delta Q}{\Delta t}$$

$$I = nqvA$$

## Materials

Density

$$\rho = \frac{m}{V}$$

Stokes' law

$$F = 6\pi\eta rv$$

Hooke's law

$$\Delta F = k\Delta x$$

Young modulus

$$\text{Stress } \sigma = \frac{F}{A}$$

$$\text{Strain } \varepsilon = \frac{\Delta x}{x}$$

$$E = \frac{\sigma}{\varepsilon}$$

Elastic strain energy

$$\Delta E_{el} = \frac{1}{2}F\Delta x$$

## Waves and Particle Nature of Light

Wave speed

$$v = f\lambda$$

Speed of a transverse wave on a string

$$v = \sqrt{\frac{T}{\mu}}$$

Intensity of radiation

$$I = \frac{P}{A}$$

Power of a lens

$$P = \frac{1}{f}$$

$$P = P_1 + P_2 + P_3 + \ldots$$

Thin lens equation

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

Magnification for a lens

$$m = \frac{\text{image height}}{\text{object height}} = \frac{v}{u}$$

Diffraction grating

$$n\lambda = d \sin\theta$$

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Refractive index

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$n = \frac{c}{v}$$

Critical angle

$$\sin C = \frac{1}{n}$$

Photon model

$$E = hf$$

Einstein's photoelectric equation

$$hf = \phi + \frac{1}{2}mv^2_{\max}$$

de Broglie wavelength

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

**Further mechanics**

Impulse

$$F\Delta t = \Delta p$$

Kinetic energy of a non-relativistic particle

$$E_k = \frac{p^2}{2m}$$

Motion in a circle

$$v = \omega r$$

$$T = \frac{2\pi}{\omega}$$

$$F = ma = \frac{mv^2}{r}$$

$$a = \frac{v^2}{r}$$

$$a = r\omega^2$$

Centripetal force

$$F = \frac{mv^2}{r}$$

$$F = mr\omega^2$$

**Fields**

Coulomb's law

$$F = k\frac{Q_1Q_2}{r^2}$$

$$\text{where } k = \frac{1}{4\pi\varepsilon_0}$$

Electric field strength

$$E = \frac{F}{Q}$$

$$E = k\frac{Q}{r^2}$$

$$E = \frac{V}{d}$$

Electric potential

$$V = k\frac{Q}{r}$$

Capacitance

$$C = \frac{Q}{V}$$

Energy stored in a capacitor

$$W = \frac{1}{2}QV$$

Capacitor discharge

$$Q = Q_0e^{-t/RC}$$

Resistor – capacitor discharge

$$I = I_0e^{-t/RC}$$

$$V = V_0e^{-t/RC}$$

In a magnetic field

$$F = BIl \sin \theta$$

$$F = Bqv \sin \theta$$

Faraday's and Lenz's laws

$$\varepsilon = \frac{-\mathrm{d}(N\phi)}{\mathrm{d}t}$$

Root-mean-square values

$$V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$$

$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$$

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## Nuclear and particle physics

In a magnetic field

$$r = \frac{p}{BQ}$$

## Thermodynamics

Heating

$$\Delta E = mc\Delta\theta$$

$$\Delta E = L\Delta m$$

Molecular kinetic theory

$$\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$$

$$pV = \frac{1}{3}Nm\langle c^2\rangle$$

Ideal gas equation

$$pV = NkT$$

Stefan-Boltzmann law

$$L = \sigma AT^4$$

$$L = \sigma 4\pi r^2 T^4$$

Wien's law

$$\lambda_{max} T = 2.898 \times 10^{-3} \text{ m K}$$

## Space

Intensity

$$I = \frac{L}{4\pi d^2}$$

Redshift of electromagnetic radiation

$$z = \frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$$

Cosmological expansion

$$v = H_0 d$$

## Nuclear radiation

Mass-energy

$$\Delta E = c^2\Delta m$$

Radioactive decay

$$A = \lambda N$$

$$\frac{dN}{dt} = -\lambda N$$

$$\lambda = \frac{\ln 2}{t_{½}}$$

$$N = N_0 e^{-\lambda t}$$

$$A = A_0 e^{-\lambda t}$$

## Gravitational fields

Gravitational force

$$F = \frac{Gm_1m_2}{r^2}$$

Gravitational field strength

$$g = \frac{Gm}{r^2}$$

Gravitational potential

$$V_{grav} = \frac{-Gm}{r}$$

## Oscillations

Simple harmonic motion

$$F = -kx$$

$$a = -\omega^2 x$$

$$x = A\cos\omega t$$

$$v = -A\omega\sin\omega t$$

$$a = -A\omega^2\cos\omega t$$

$$T = \frac{1}{f} = \frac{2\pi}{\omega}$$

$$\omega = 2\pi f$$

Simple harmonic oscillator

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

$$T = 2\pi\sqrt{\frac{l}{g}}$$

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