Physics

Sample

Marking Scheme

This marking scheme has been prepared as a **guide only** to markers. This is not a set of model answers, or the exclusive answers to the questions, and there will frequently be alternative responses which will provide a valid answer. Markers are advised that, unless a question specifies that an answer be provided in a particular form, then an answer that is correct (factually or in practical terms) **must** be given the available marks.

If there is doubt as to the correctness of an answer, the relevant NCC Education materials should be the first authority.

Throughout the marking, please credit any valid alternative point.

Where markers award half marks in any part of a question, they should ensure that the total mark recorded for the question is rounded up to a whole mark.

Answer ALL questions

Marks

Question 1

a) A football is dropped from a helicopter that is flying horizontally with a velocity of $100ms^{-1}$ at a height of 250m.

i) What horizontal distance does the football cover before hitting the ground? **2**

$s = ut + \frac{1}{2}at^2$ $250 = \frac{1}{2} \times 9.81 \times t^2$ $t = 7.10$ s (1)
Horizontal distance travelled is equal to 100 x 7.10 = 710 m (1)

ii) A girl kicks the football along the ground at a wall 1.5m away. The ball strikes the wall normally and rebounds in the opposite direction, the girl who has not moved, stops the ball a short time later. **2**

Explain why the final displacement of the ball is not 3m.

Displacement is a vector (1)
The ball has travelled in the opposite direction back to its original position (1)

b) State the difference between a vector and scalar quantity **1**

Vector quantities have magnitude and direction. Scalar quantities have magnitude only.

c) Give on example of a vector quantity (other than force) and one example of a scalar quantity. **2**

vector quantity : Displacement, acceleration, velocity etc…
scalar quantity : Distance, speed, mass etc…

d) A cyclist accelerates uniformly from rest to a speed of 8ms-1 in 25s then brakes at uniform deceleration to a halt in a distance of 22m.

i) For the first part of the journey, calculate the acceleration. **2**

a = (v-u)/t , substitution a = (8 – 0) / 25 (award 1 mark)
a = 0.32 m (award 1 mark)

ii) For the first part of the journey calculate the distance travelled **2**

$s = ut + 1/2at^2$, substitution $s = (0 \times 25) + (0.5 \times 0.32 \times 22^2)$. (award 1 mark)
s = 77.44 m (award 1 mark)

Marks

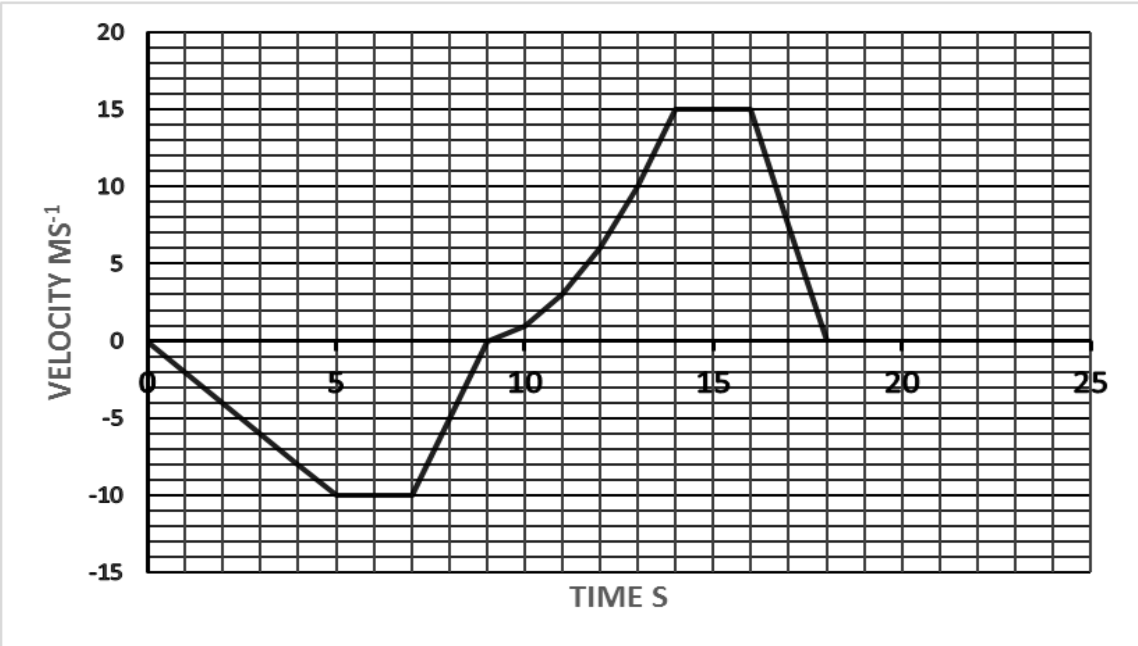
iii) For the second part of the journey, calculate the deceleration. **2**

$v^2 = u^2 + 2as$, substitution $0 = 82 + 2 \times a \times 22$, $-64 = 44a$
$a = -64 / 48$ $a = -1.33ms^{-2}$ ($-1.3ms^{-2}$)

e) If an object moves in a circle, then what is the name of the force which is stopping the object flying off in a straight line? **1**

centripetal force

f) The graph below shows how the velocity of a toy car moving in a straight line varies over time.



i) Describe the motion of the car in the following regions of the graph.

AB BC CD DE EF FG

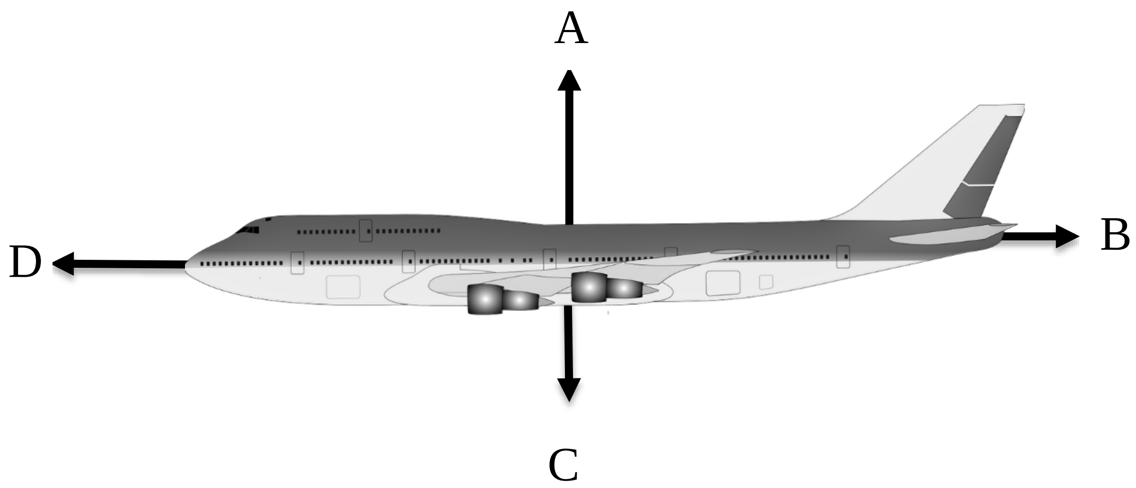
AB – Constant acceleration from rest in the opposite direction (1)
BC – Constant velocity (1)
CD – Constant deceleration to rest (1)
DE – Increasing acceleration (1)
EF – Constant velocity (1)
FG – Constant deceleration to rest (1)

Total 20 Marks

Marks

Question 2

a) The diagram shows an aeroplane travelling at a constant velocity following a horizontal trajectory.



i) Name the forces A,B,C and D acting on the aeroplane. **2**

A – Lift
B – Air resistance
C – Weight / gravity
D – Thrust / Engine force

2 marks for the correct naming of all four forces, 1 mark for correctly naming two or three forces, 0 marks for correctly naming 1 or 0 forces.

ii) By using Newton's Laws of motion, explain why the aeroplane is travelling at constant velocity. **2**

Vector sum of all forces zero (no resultant force). (award 1 mark)
Therefore by Newton's second law there is zero acceleration (award 1 mark)

iii) After five minutes the forces change on the aeroplane. This results in a forward acceleration of $75ms^{-2}$.If the mass of the aeroplane is 52 000 Kg then calculate the magnitude of the new resultant force. **2**

F=ma, Substitution F = 52000 x 75 (award 1 mark)
F = 3900000N or 3.9 x 10^{6}N (award 1 mark)

iv) Calculate the work done by the jet engines if the aeroplane travels 5.5km during this period of acceleration. **2**

work done = force x distance, substitution WD = 3900000 x 5500 = (award 1 mark)
Wd = 21450000000J or 2.145 x 10^{10}J (award 1 mark)

Marks

b)

i) State the law of conservation of momentum. **1**

The total momentum of a closed system does not change.

ii) What quantity is not conserved in an inelastic collision? **1**

Kinetic energy

iii) A gun has a mass of 2.0kg and a recoil velocity of 9ms-1. What is the velocity of the bullet if it has a mass of 0.02kg? **3**

momentum = mass x velocity, for the gun, substitution
momentum = 2 x 9 = 19 kgms^{-1} (award 1 mark)
Because momentum is conserved, for the bullet, substitution
19 = 0.02 x v (award 1 mark)
v = 950 ms^{-1} (award 1 mark)

iv) Determine the rotational kinetic energy of an electric motor if its angular velocity is 100 π rads-1 and its moment of inertia is 50 kgm^2. **2**

E_k= ½ x I x $\dot{\omega}^2$ $\dot{\omega}$ =100 πrads^{-1} I= 50kgm^2 substitution E_k = ½ x 100 x 50
(award 1 mark)
E_k= 2500J (award 1 mark)

c) A ball has a mass 0.20kg and is dropped from an initial height of 1.5m. After impact with the ground, the ball rebounds to a height of 0.85m.

i) Calculate the speed of the ball immediately before impact. **2**

Ek gain =Ep loss, 1/2xmxv^2 = mgΔh, substitution
0.5x0.2xv^2=0.2x9.81x1.5 (award 1 mark)
v^2 = 29.93 v = 5.423ms^{-1} (5.4ms^{-1}) (award 1 mark)

ii) Calculate the speed of the ball immediately after the impact. **2**

initial Ek of ball = final Ep of ball, 1/2xmxv^2 = mxgxh, substitution
0.5xv^2=9.81x0.85
v = 4.084ms^{-1} (4.1ms^{-1})

iii) The dissipated energy from the ball ends up where? **1**

ground or air or surroundings (award 1 mark for any valid answer)

Total 20 Marks

Marks

Question 3

a) A body is in simple harmonic motion of amplitude 0.6m and period 4π seconds. What is the speed of the body when the displacement of the body is 0.3m? **2**

$v=2\pi f\sqrt{(A^2 - x^2)}$ and $f = 1/T$, therefore $v=(2\pi/T) \times \sqrt{(A^2 - x^2)}$, substitution
$v=(2\pi/4\pi) \times \sqrt{(0.6^2) - 0.3^2)}$ (award 1 mark)
$v = 0.2598\ ms^{-1}(0.3ms^{-1})$ (award 1 mark)

b) A particle of mass 6.0 x 10^{-3} kg, moving with simple harmonic motion of amplitude 0.15m, takes 52s to make 50 oscillations. What is the maximum kinetic energy of the particle? **2**

$Ek = ½ \times m \times v_{max}^2$, substitution $Ek = ½ \times m \times (2\pi f \times \sqrt{(a^2-x^2)})$, substitution
$Ek= 0.5x6.0x10^3x(2x\pi x(50/52)x\sqrt{0.15^2-0^2})$
$Ek = 0.00246$ J (0.0025J or 2.5 x 10^{-3}J

c) Define Thermal energy. **1**

The energy of a substance or system in terms of the motion or vibration of its molecules

d) A metal rod has a length of 100cm at 200°C. At what temperature will its length be 99.4cm if the linear expansivity of the material of the rod is 0.00002/K? **3**

$[_t = l_0(1 + \alpha t)$, substitution $1=l_0(1+0.00002x200)$, $0.994=l0(1+0.00002xt)$
Divide equations to cancel l_0, $1 + \alpha t = 0.994 + 0.003976$ (award 1 mark)
$t = -102^oC$ (award 1 mark)

e)

i) Calculate the efficiency of a reversible heat engine operating between a hot reservoir at 900K and a cold reservoir at 500K. **2**

ή= 1 - T2 / T1, substitution =1 – 500/900 (award 1 mark)
ή= 44.4% (award 1 mark)

ii) The temperature of one of the heat reservoirs can be changed by 100 degrees kelvin up or down. What is the highest efficiency that can be achieved by making this temperature change? **2**

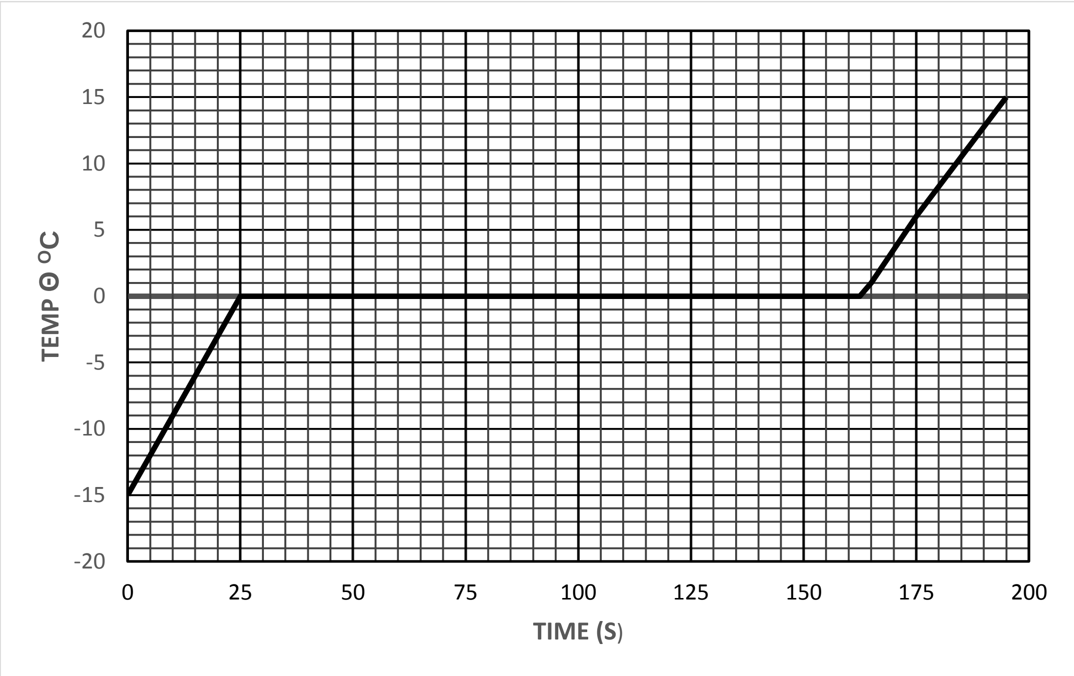
ή= 1 - T2 / T1, substitution =1 – 400/900 (award 1 mark)
ή= 55.55% (award 1 mark)

iii) Explain thermal equilibrium by reference to the behaviour of the molecules when a sample of hot gas is mixed with a sample of cooler gas and thermal equilibrium is reached. **2**
(kinetic) energy is exchanged in molecular collisions (1) until average kinetic energy of all molecules is the same (1)

Marks

f) A quantity of crushed ice is removed from a freezer and placed in a calorimeter. Thermal energy is supplied to the ice at a constant rate. To ensure that all the ice is at the same temperature, it is continually stirred. The temperature of the contents of the calorimeter is recorded every 15 seconds.

The graph below shows the variation with time t of the temperature θ of the contents of the calorimeter.



i) From the graph above, state the coordinates of the data point at which all the ice has just melted. **1**

Point on graph has coordinates (162.5,0)

ii) Explain with reference to the energy of the molecules, the constant temperature region of the graph. **3**

Look for the following points:
-to change phase, the separation of the molecules must increase;Some recognition that the ice is changing phase is needed (award 1 point.)
-so all the energy input goes to increasing the PE of the molecules; Accept something like "breaking the molecular bonds" (award 1 point)
-KE of the molecules remains constant, hence temperature remains constant; If KE mentioned but not temperature then assume they know that temperature is a measure of KE. (award 1 point]

iii) The mass of ice is 0.25kg and the specific heat capacity of water is 4200Jkg^{1}K^{-1}. **2**
Use this data and data from the graph to deduce that the energy is supplied to the ice at a rate of approximately 485W.

energy required = msΔθ= 0.25 x 15 x 4200 = 15750J (award 1 mark)
Power = Energy / time = 15750 / 32.5 = 484.6W (award 1 mark)

Total 20 Marks

Question 4

Marks

a) The distance between an electron and a point positive charge P of 5uC is 40mm. Given that the charge on an electron is 1.6x10-19 C, calculate the magnitude of the force on the positive charge due to the electron. (permittivity of free space *ε_0= 8.85 x 10-12 Fm^{-1})* **2**

$F = Q_1Q_2 / 4\pi\varepsilon_0 r^2$, sub, $F =(1.6\times10^{-19} \times 5.0 \times 10^{-4})/(4\pi \times 8.85 \times 10^{-12} \times (0.004)^2)$ (award 1 mark)
$F = 4.5 \times 10^{-12}$ N (award 1 mark)

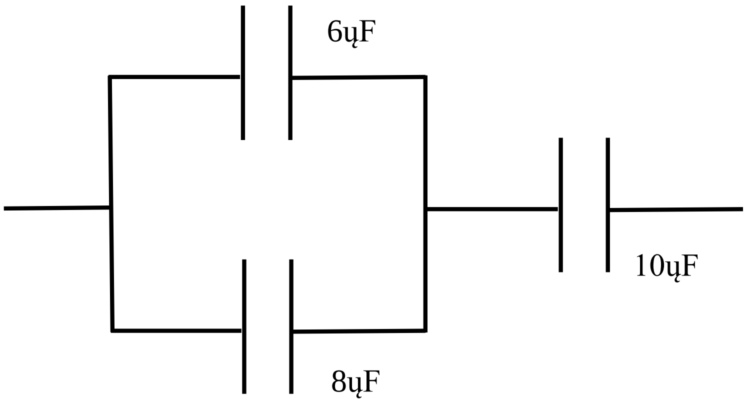
b) At a point where the distance r from a point charge is 60mm, an electric field has a strength of 2.5 x 104 Vm^{-1}. Calculate the potential at this point. **2**

Sub, $V= Q / 4\pi\varepsilon_0 r$ into $E = Q / 4\pi\varepsilon_0 r^2$, Therefore $E = V /r$ (award 1 mark)
$E = 2.5 \times 10^4 / 6.0 \times 10^{-3} = 1500$ V (award 1 mark)

c) Define the capacitance of a capacitor. **2**

C= Q/V or Ration of the charge stored in the capacitor (award 1 mark) to the p.d across it (award 1 mark)

d) In the diagram below three capacitors have been connected together. Find the equivalent capacitance of the combination of capacitors shown. **3**



First calculation of the two capacitors in parallel, C = 6 + 8 , C = 14ųF (award 1 mark)
Then consider the series combination, 1 / C = 1 /14 + 1/10 , C = 5.8 ųF (award 2 marks)

e) A set of decorative lights consists of a string of lamps. Each lamp is rated at 10V, 0.7W and is connected in series to a 230V supply. Calculate

i) the number of lamps in the set, so that each lamp operates at the correct rating **1**

Number of lamps = 230 / 10 = 23 (award 1 mark)

ii) the current in the circuit **1**

Using P = IV, I = 0.7 / 10 = 0.070A. (award 1 mark)

Marks

iii) the resistance of each lamp **1**

$R = I / V = 10 / 0.070 = 142.9\Omega$ or $R = V^2 / P = 100 / 0.7 = 142.9\Omega$.

iv) the total energy transferred by the set of lights in 4 hours. **2**

Conversion of 4 hours into seconds (4 x 60 x 60) (award 1 mark)
$E_T = 0.7 \times 23 \times (4 \times 60 \times 60) = 2.31 \times 10^5$J (award 1 mark)

f) A lamp is rated at 12V, 9W.

i) How many joules of energy are transferred by the lamp in 5 minutes? **2**

Conversion of 5 minutes into seconds (5 x 60) (award 1 mark)
$E = P \times t$, sub $E = 9 \times (5 \times 60) = 2700$J (award 1 mark)

ii) Calculate the current passing through the lamp when it is connected to the 12V supply. **2**

$P = I \times V$, $I = P / V$, $I = 9 / 12 = 0.75$ (award 1 mark)

Units of current – A (award 1 mark)

iii) Calculate the resistance of the lamp when it is connected to the 12V supply. **2**

P = V2 / R, sub, R = V2 / P, = 122 / 9 = 16.
Or $V = I \times R$, sub $R = V / I = 12 / 0.75 = 16$ (award 1 mark for either answer)
Units for resistance Ohms or Ω (award 1 mark)

Total 20 Marks

Marks

Question 5

a) Explain why a charged particle, moving with a constant speed v perpendicular to a uniform magnetic field B, will follow a circular path. **1**

The force on the particle is always perpendicular to v *(award 1 mark)*

b) A circular coil of diameter 120 mm has 750 turns. It is placed so that its plane is perpendicular to a horizontal magnetic field of uniform flux density 45 mT.

i) Calculate the magnetic flux passing through the coil when in this positions. **2**

Φ (= *BA*) = $45 \times 10^{-3} \times \pi \times (60 \times 10^{-3})^2$ *(award 1 mark)*
= 5.089×10^{-4} Wb (1) (5.09×10^{-4} Wb *(award 1 mark)*

c) The coil in question (b) is rotated through 90^o about a vertical axis in a time of 150ms. Calculate

i) the change of magnetic flux linkage produced by this rotation. **2**

$N\Delta\Phi$ (= NBA - 0) = 750 × 5.09×10^{-4} (1) = 0.382(Wb turns) (1) (award 1 mark)
units for magnetic flux linkage - Wb turns (award 1 mark)

ii) the average emf induced in the coil when its is rotated. **2**

induced emf ($N\frac{\Delta\Phi}{\Delta t}$) = 0.382 / 0.15 (award 1 mark)
induced emf = 2.55V (award 1 mark)

d) A magnetic field is produced around a current carrying wire. What is the strength of the magnetic field at a point P about 3.8 cm from the centre of the wire if the current flowing in the wire is 4.2A? **3**

$B = \mu_o I / 2\pi r$, sub, $B = 4\pi \times 10^{-7} \times 4.2/ (2 \times \pi \times 0.038)$ (award 1 mark)
$B = 5.5 \times 10^{-6}$(award 1 mark)
Units for magnetic field strength – T (award 1 mark)

e) A piano is being lifted vertically at a constant speed to the top of a build by a cable attached to a crane. The piano has a mass of 750kg.

i) With reference to one of Newton's laws of motion, explain why the tension, T in the cable must be equal to the weight of the piano. **4**

resultant force on crane is zero (award 1 mark)
forces must have equal magnitudes or sizes (award 1 mark)
but act in the opposite direction (award 1 mark)
Correct statement of 1st or 2nd law (award 1 mark)

Marks

f) The piano in question (e) is lifted through a vertical height of 12.0m in 5.5s. Calculate

i) the work done on the piano. **2**

Work Done = Force x distance = 750 x 9.81 x 12.0 (award 1 mark)
Work done = 8.83 x 104J (award 1 mark)

ii) The power output of the crane in this situation. **2**

Power = Work Done / time = 8.83 x 104 / 5.5 (award 1 mark)
1.6054 x 10^4 W (award 1 mark)

g) Calculate the height through which a 5kg mass would need to drop to lose the same energy as 100W light bulb would radiate in 1 min. **2**

Energy radiated by light bulb = loss of GPE, 100 x 60 = 5 x 9.81 x ΔH (award 1 mark)
ΔH = 122.3m (award 1 mark)

Total 20 Marks

End of paper

Marks

Formulae and data sheet

Fundamental constants and values

Quantity	Symbol	Value	Units
Speed of light in a vacuum	c	3.00×10^{8}	ms^{-1}
Permeability of free space	u_0	$4\pi \times 10^{-7}$	Hm^{-1}
Permittivity of free space	ε_0	8.85×10^{-12}	Fm^{-1}
Magnitude of the charge of electron	e	1.60×10^{-19}	C
The Planck constant	h	6.63×10^{-34}	Js
gravitational constant	G	6.67×10^{-11}	$Nm^{2}kg^{-2}$
Avogadro constant	$N_A \cdot$	6.02×10^{23}	Mol^{-1}
Molar gas constant	R	8.31	$JK^{-1}mol^{-1}$
The Boltzmann constant	k	1.38×10^{-23}	JK^{-1}
The Stefan constant	σ	5.67×10^{-8}	$Wm^{-2}K^{-4}$
The Wien constant	α	2.90×10^{-3}	mK
Electron rest mass	m_e	9.11×10^{-31}	Kg
Electron charge/mass ration	e / m_e	1.76×10^{11}	Ckg^{-1}
Proton rest mass	m_p	$1.67(3) \times 10^{-27}$	Kg
Proton charge/mass ratio	e/m_p	9.58×10^{7}	Ckg^{-1}
Neutron rest mass	m_n	$1.67(5) \times 10^{-27}$	kg
Gravitational field strength	g	9.81	Nkg^{-1}
Acceleration due to gravity	g	9.81	ms^{-2}
Atomic mass unit	u	1.661×10^{-27}	kg

Electricity

Current and pd	$I = \frac{\Delta Q}{\Delta t}$ $V = \frac{W}{Q}$	$R = \frac{V}{I}$
emf	$\varepsilon = \frac{E}{Q}$	$\varepsilon = I(R + r)$
resistors in series	$R = R_1 + R_2 + R_3 + \ldots\ldots\ldots$	
resistors in parallel	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$	
resistivity	$\rho = \frac{RA}{L}$	
power	$P = VI = I^2R = \frac{V^2}{R}$	

Marks

Formulae and data sheet – Mechanics

	Moments	moments = Fd	
	Velocity and acceleration	$v = \frac{\Delta s}{\Delta t}$	$a = \frac{\Delta v}{\Delta t}$
	Equation of motion	$v = u + at$	$s = \frac{(u+v)}{2}t$
		$v^2 = u^2 + 2as$	$s = ut + \frac{at^2}{2}$
	Force	$F = ma$	
	Work, energy and power	$W = Fs\cos\theta$	$E_k = {}^1/_2\, mv^2$
		$P = \frac{\Delta W}{\Delta t}$, $P = Fv$	$\Delta E_p = mg\Delta h$
		$efficiency = \frac{useful\ output\ power}{input\ power}$	
	Momentum	force $F = \frac{\Delta(mv)}{\Delta t}$ Impulse $F\Delta t = \Delta(mv)$	
Circular Motion	angular velocity	$\omega = \frac{v}{r}$	$\omega = 2\pi f$
	Centripetal acceleration	$a = \frac{v^2}{r} = \omega^2 r$	
	Centripetal force	$F = \frac{mv^2}{r} = m\omega^2 r$	
	Moment of inertia	$I = \sum mr^2$	
	Angular kinetic energy	$E_k = \frac{1}{2}I\omega^2$	
	Equation of angular motion	$\omega_2 = \omega_1 + at$ $\omega_2^2 = \omega_1^2 + 2a\theta$ $\theta = \omega_1 t + \frac{1}{2}at^2$ $\theta = \frac{1}{2}(\omega_1 + \omega_2)t$	
	Torque	$T = Ia$	
	Angular momentum	angular momentum = $I\omega$	
	Work done	$W = T\theta$	
	Power	$P = T\omega$	

Marks

Formulae and data sheet - Mechanics Continued

Oscillations	acceleration	$a = -(2\pi f)^2 x$
	Displacement	$x = Acos\,(2\pi ft)$
	Speed	$v = \pm 2\pi\sqrt{A^2 - x^2}$
	Maximum speed	$v_{max} = 2\pi fA$
	Maximum acceleration	$a_{max} = (2\pi f)^2$A
	For a mass-spring system	$T = 2\pi\sqrt{\frac{m}{k}}$
	For a simple pendulum	$T = 2\pi\sqrt{\frac{l}{g}}$
Thermodynamics		$Q = \Delta U + W$
		$W = p\Delta V$
	Adiabatic change	$pV^t = constant$
	Isothermal change	$pV = constant$
Heat engines		efficiency = $\frac{W}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}}$
		maximum efficiency = $\frac{T_{H-}T_C}{T_H}$
		Work done per cycle = area of loop
		input power = calorific value x fuel flow rate
		Indicated power = $(area\ of\ p -\ V\ loop)x$ $(no.of\ cycles\ per\ second)x$ $number\ of\ cylinder$s
		Output of brake power $P = T\omega$
		Friction power = $indicated\ power - brake\ power$
Heat pumps and refrigerators	Refrigerator	$COP_{ref} = \frac{Q_{out}}{W} = \frac{Q_{out}}{Q_{in} - Q_{out}}$
	Heat pump	$COP_{hp} = \frac{Q_{in}}{W} = \frac{Q_{in}}{Q_{in} - Q_{out}}$

Marks

Formulae and data sheet - Mechanics Continued

Electric Fields and Capacitors	Force between two points charges	$F = \frac{1}{4\pi\varepsilon_o}\frac{Q_1 Q_2}{r^2}$
	Force on a charge	$F = EQ$
	Field strength for a uniform field	$E = \frac{V}{d}$
	Field strength for a radical field	$E = \frac{Q}{4\pi\varepsilon_0 r^2}$
	Electrical potential	$\Delta W = Q\Delta V$
		$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$
	Capacitance	$C = \frac{Q}{V}$
	Decay of charge	$Q = Q_o e^{\frac{-t}{RC}}$
	Time constant	RC
	Capacitor energy stored	$E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$
Electrons in a field		$F = \frac{eV}{d}$ $F = Bev$ $r = \frac{mv}{Be}$
		$\frac{1}{2}mv^2 = eV$ $\frac{QV}{d} = mg$ $F = 6\pi\eta rv$
Magnetic field	Force on a current	$F = BIl$
	Force on a moving charge	$F = BQv$
	Magnetic flux	$\phi = BA$
	Magnetic flux linkage	$N\phi = BAN$
	Magnitude of induced emf	$\varepsilon = N\frac{\Delta\phi}{\Delta t}$
	Emf induced in a rotating coil	$N\phi = BANcos\theta$ $\varepsilon = BAN\omega\sin\omega t$
	Transformer equation	$\frac{N_s}{N_p} = \frac{V_s}{V_p}$ $efficiency = \frac{I_s V_s}{I_p V_p}$
Gas and thermal physics	gas law	$pV = nRT$ $pV = NkT$
	Kinetic theory model	$pV = \frac{1}{3}Nm(c_{rms})^2$
	Kinetic energy of gas molecules	$\frac{1}{2}m(c_{rms})^2 = \frac{3}{2}kT = \frac{3RT}{2N_A}$
	Energy to change temperature	$Q = mc\Delta T$
	Energy to change state	$Q = ml$

Learning Outcomes matrix

Question	Learning Outcomes assessed	Marker can differentiate between varying levels of achievement
1	1,	Yes
2	4,2	Yes
3	6,5	Yes
4	7,8	Yes
5	9,3	Yes

Grade descriptors for Physics

Learning Outcome	Pass	Merit	Distinction
Understand the mechanics of motion	Demonstrate adequate level of understanding	Demonstrate robust level of understanding	Demonstrate highly comprehensive level of understanding
Understand the mechanics of forces	Demonstrate adequate level of understanding	Demonstrate robust level of understanding	Demonstrate highly comprehensive level of understanding
Understand the mechanics of energy	Demonstrate adequate level of understanding	Demonstrate robust level of understanding	Demonstrate highly comprehensive level of understanding
Understand the mechanics of momentum	Demonstrate adequate level of understanding	Demonstrate robust level of understanding	Demonstrate highly comprehensive level of understanding
Understand the mechanics of periodic motion	Demonstrate adequate level of understanding	Demonstrate robust level of understanding	Demonstrate highly comprehensive level of understanding
Understand the basic principles of thermal physics	Demonstrate adequate level of understanding	Demonstrate robust level of understanding	Demonstrate highly comprehensive level of understanding
Understand the fundamentals of electrostatics	Demonstrate adequate level of understanding	Demonstrate robust level of understanding	Demonstrate highly comprehensive level of understanding
Understand the fundamentals of electrodynamics	Demonstrate adequate level of understanding	Demonstrate robust level of understanding	Demonstrate highly comprehensive level of understanding
Understand the fundamentals of magnetism	Demonstrate adequate level of understanding	Demonstrate robust level of understanding	Demonstrate highly comprehensive level of understanding