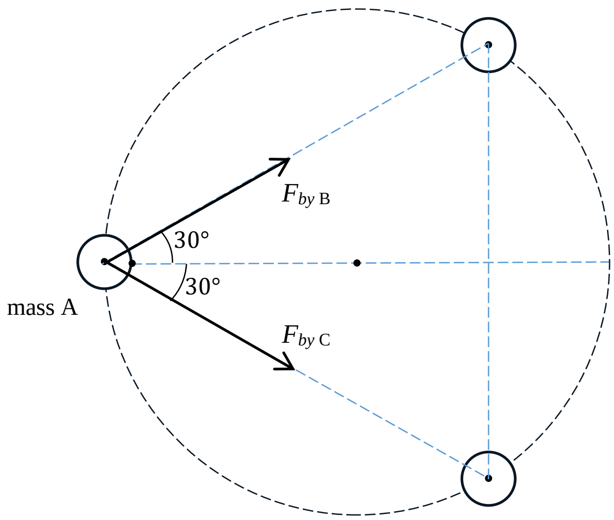
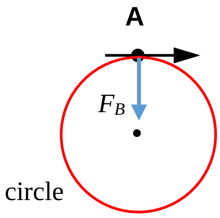
2024 HCI Preliminary Examination Paper 2 Suggested Solutions

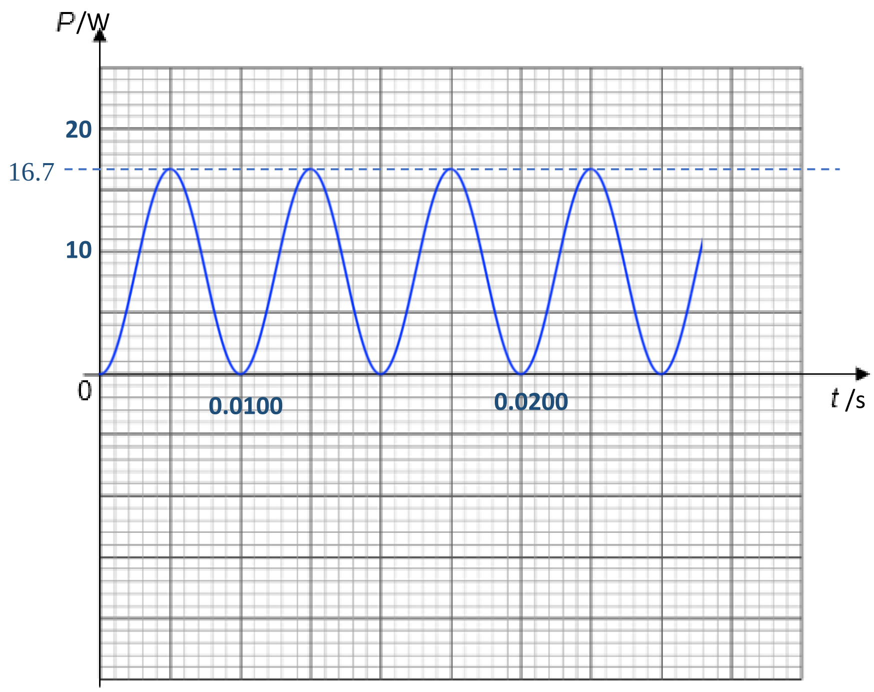
Q1		
(a)	During the collision, there are <u>no external forces acting on the photon and electron or system</u>, hence linear momentum is conserved.	**B1**
(b)(i)	**1.** $\sum p_x = 7.30 \times 10^{-22}\ \text{kg m s}^{-1}$	**B1**
	2. $\sum p_Y = 0\ \text{kg m s}^{-1}$	**B1**
(b)(ii)	By principle of conservation of linear momentum, $(\rightarrow)\ 7.3 \times 10^{-22} = (p_p)(\cos 60^o) + (p_e)(\cos 25^o)$ ...(1) $(\uparrow)\ (p_e)(\sin 25^o) = (p_p)(\sin 60^o)$ ...(2) Solving (1) and (2) gives, $\dfrac{(p_p)(\sin 60°)}{(p_p)(\cos 60°)} = \tan 60° = \dfrac{(p_e)(\sin 25°)}{(7.3 \times 10^{-22}) - (p_e)(\cos 25°)}$ $\Rightarrow p_e = 6.35 \times 10^{-22}\ \text{kg m s}^{-1}$ M1, M1 – 2 equations showing application of COLM A1 – final answer after solving two equations.	**M1** **M1** **A1**

Q2		
(a)	Every **point mass attracts** every other **point mass** with a **force** that is directly **proportional to the product of their masses** and **inversely proportional to the square of the distance between them**.	B1 B1
(b)(i)	 The vertical components of the two forces due to B and C cancel each other, hence, Resultant force in the y-direction = 0 Hence, Resultant force F = Resultant force in the x-direction $= 2\times\dfrac{GM^2}{d^2}\times\cos 30° = 2\times\left(\dfrac{6.67\times10^{-11}\left(6.20\ x\ 10^{24}\right)^2}{\left(1.32\times10^{9}\ \right)^2}\right)\times\cos 30° = 2.5487\times10^{21}$ N $=2.55\times10^{21}$ N Alternative methods accepted.	 B1 M1
(b)(ii)	The resultant gravitational force **provides** for the centripetal force required for the rotation of planet A.	B1
	$F = m\omega^2 R$ $\omega=\sqrt{\dfrac{F}{mR}}=\sqrt{\dfrac{2.5487\times10^{21}}{6.20\times10^{24}\times7.60\times10^{8}}}=7.3546\times10^{-7}$ rad s^{-1} $T=\dfrac{2\pi}{\omega}=\dfrac{2\pi}{7.3546\times10^{-7}}=8.54\times10^{6}$ s	 M1 A1
(b)(iii)	The gravitational **potential is set to be <u>zero at infinity</u>**. Gravitational force is **<u>attractive</u>** in nature and **<u>the force exerted on a test mass by the external agent will be in opposite direction to the displacement of the mass</u>**. Thus negative work is done by the external force (to bring a test mass from infinity to the point and hence potential is negative). <u>OR</u> The gravitation potential is set to be **<u>zero at infinity</u>**.	B1 B1 **OR** B1

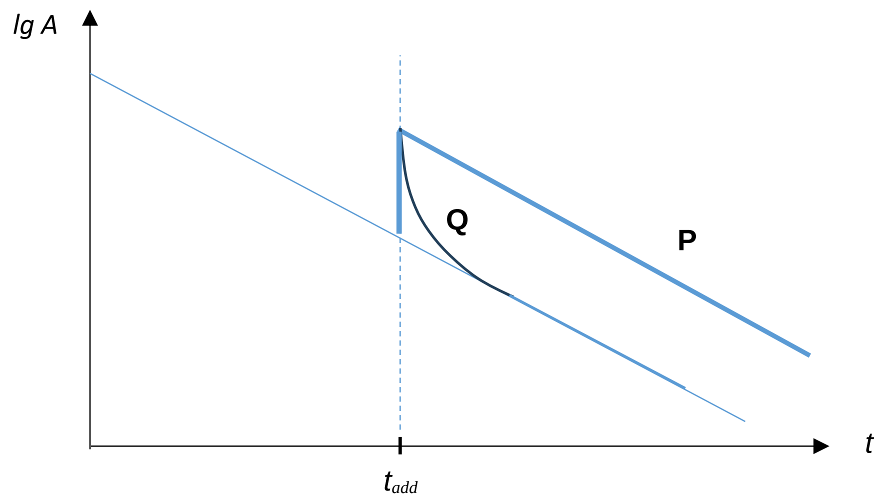
	Since gravitational force is **attractive** in nature, (positive**) work is done by an external agent to bring a (test) mass from the point** (in the field if these 3 planets**) to infinity**, hence the (initial) potential is therefore (lower than at infinity and hence) negative.	**B1**
(b)(iv)	$U = U_{AB} + U_{AC} + U_{BC}$ $= -\frac{Gm^2}{d} + \left(-\frac{Gm^2}{d}\right) + \left(-\frac{Gm^2}{d}\right)$ $= 3 \times \left(-\frac{6.67 \times 10^{-11} \left(6.20\ x\ 10^{24}\right)^2}{1.32 \times 10^9}\right)$ $= -5.83 \times 10^{30}$ J	 **M1** **A1**

Q3		
(a)	A polarised wave is one in which the vibrations/oscillations of the wave are restricted to only one direction in the plane normal/perpendicular to the direction of energy transfer.	**B1** **B1**
(b)(i)	As long as polarising filter B is perpendicular to either polarising filter A or filter C, the emergent light from filter C will be zero. Hence, the other angle that occurs will be when polarising axis of B is 90° of C, i.e. $\theta = 135°$	**A1**
(b)(ii)	Using Malus' Law, Intensity of light emergent from polarising filter B = $I\cos^2(60°)$ Intensity of light emergent from polarising filter C = $I\cos^2(60°)\cos^2(60° - 45°)$ = $0.233\,I$	**M1** **A1**

Q4		
(a)(i)	 (Use FLHR to get the direction of force – the force will provide for centripetal acceleration for circular motion as it is always perpendicular to the velocity and hence points towards centre of circle. The center of circle should be below point A) <u>Complete circle with centre of circle vertically below point A and the arrow tangential to the circle.</u>	B1
(a)(ii)	The <u>magnetic force provides for the centripetal force</u> required for circular motion,	B1
	$Bqv = \frac{mv^2}{R} \quad \Rightarrow R = \frac{mv}{Bq} = \frac{(9.11\times10^{-31}\text{ kg})(2.8\times10^{7}\text{ m s}^{-1})}{(1.2\times10^{-3}\text{ T})(1.60\times10^{-19}\text{ C})} = 0.133\text{ m}$ = 13 cm (shown)	M1
(b)(i)1	Direction of electric field is downward in the plane of the paper.	A1
(b)(i) 2	For the electron to be undeflected, the net force on it must be zero. $qvB = qE$ $\Rightarrow \quad E = vB = (2.8\times10^{7})(1.2\times10^{-3})$ $= 3.36\times10^{4}\text{ N C}^{-1}$	M1 A1
(b)(ii)	<u>Helix</u> (out of the plane of the paper) with an <u>increasing pitch</u> *Remarks :* • Spiral not accepted as answer. Spiral is not helix – a spiral has a changing radius. • "Increasing pitch" can be marked from the diagram if it is included. But at least four turns needs to be drawn for any credit.	B1 B1

Q5		
(a)(i)	$\omega = \frac{2\pi}{T} = 628 \Rightarrow T = 1.00 \times 10^{-2}$ s	A1
(a)(ii)	$V_{rms} = \frac{V_0}{\sqrt{2}} = \frac{15}{\sqrt{2}} = 10.6$ V = 11 V	A1
(a)(iii)	$\frac{1}{R_{eff}} = \frac{1}{12.0} + \frac{1}{3.0+6.0} = \frac{7}{36} \Rightarrow R_{eff} = 5.1429\ \Omega$	M1
	$I_0 = \frac{V_0}{R} = \frac{15}{5.1429} = 2.92$ A = 2.9 A	A1
(a)(iv)	V_{rms} across 6.0 Ω resistor = $\frac{V_0}{\sqrt{2}} = \frac{(15 \times \frac{6.0}{9.0})}{\sqrt{2}} = \frac{10.0\text{ V}}{\sqrt{2}} = 7.071$ V	M1
	Mean power = $\frac{V^2}{R} = \frac{7.071^2}{6.0} = 8.33$ W = 8.3 W	A1
(b)	 $P_0 = 8.33 \times 2 = 16.7\ W$	
	B1 : Correct shape (sin² graph) *B1: at least 2 cycles shown with period labelled correctly (t ≥ 2T i.e. 4 maximum power in graph)* *B1: correct peak value labelled on graph.*	B3

Q6		
(a)(i)	Gain in kinetic energy of electron = Loss in EPE of system $\frac{1}{2}mv^2 - 0 = eV$ $v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2(1.6 \times 10^{-19})(100)}{9.11 \times 10^{-31}}} = 5.93 \times 10^6 \text{ m s}^{-1}$	**M1** **A1**
(a)(ii)	$\lambda = \frac{h}{p} = \frac{(6.63 \times 10^{-34})}{(9.11 \times 10^{-31})(5.93 \times 10^6)}$ $= 1.23 \times 10^{-10} \text{ m}$	**M1** **A1**
(b)(i)	$2d \sin \theta$	**B1**
(b)(ii)1.	The electrons emerge with a larger speed/kinetic energy and hence momentum.	**B1**
	By de Broglie relationship ($\lambda = \frac{h}{p}$), the wavelength of the electrons decreases.	**B1**
(b)(ii)	The path difference of the electron waves (from the different atomic planes) arriving at the detector remains constant, however the wavelength of the electrons decreases continually.	**B1**
	When the path difference is integer multiple of the de Broglie wavelength of the electrons (0, λ, 2λ, …..), constructive interference occurs/ the electron waves meet in phase,	**B1**
	the likelihood/chance/probability of the electrons arriving at the detect is large and a maximum value of I is detected.	**B1**
	B1 - path difference is constant *B1 - CI /maxima occurs when path difference is integer multiple of the wavelength of the electrons.* *B1 – maxima corresponds to high chance probability of electron arriving there*	

Q7		
(a)	The half-life of a radioactive nuclide is the <u>average time</u> taken for half of the original <u>number</u> of nuclei in a sample of the radioactive nuclide to decay. Or the activity of a sample of the radioactive nuclide to halve.	**B1**
(b)	Activity is the number of disintegrations per unit time.	**B1**
(c)(i)	Half-life = 12.5 h = 12.5 × 60 × 60 = 45000 s Decay constant $= \frac{\ln 2}{\text{half-life}} = \frac{\ln 2}{45000}$ $= 1.54 \times 10^{-5}\ \text{s}^{-1}$	**B1** **M1** **A1**
(c)(ii)	$A = \lambda N = \frac{\ln 2}{T_{1/2}}(0.22N_0) = \frac{\ln 2}{(12.5 \times 60 \times 60)}(0.22N_0)$ $= 3.39 \times 10^{-6} N_0\ \text{Bq}$	**M1** **A1**
(d)(i) and (ii)	 For P, the gradient is the negative of the decay constant. Same nuclide same decay constant and hence same gradient. For Q with a very much shorter half-life compared to K-42, it will approach the original graph quite quickly. ($A = A_{10}e^{-\lambda_1 t} + A_{20}e^{-\lambda_2 t}$. Cannot linearise to give a straight line.)	 **B1** **B1**

Q8		
(a)(i)	From graph, when v = 25 m s^{-1}, P = 500 W	B1
(a)(ii)	$P = Fv$ $F = \frac{P}{v} = \frac{500}{25} = 20$ N	M1 A1
(a)(iii)	At constant velocity, the net force on the rider is zero. Furthermore, F_{slope} = 0 since the ground is level. Hence, the propulsive force = the drag force F_{air} ρ = 1.0 x 10^{-3} g cm^{-3} = $\frac{1.0\times10^{-3}\times10^{-3}}{10^{-6}}\frac{\text{kg}}{\text{m}^3} = 1.0$ kg m^{-3} $F_{air} = \frac{1}{2}\rho C_D A v^2$ $20 = \frac{1}{2}(1.0)(C_D A)(25^2)$ Effective drag area, $C_D A = 0.064\text{m}^2$ C1 – appreciate that F_{air} = F allow mark as long as 20 N is substituted for M1 – for correct conversion of density to kg m^{-3} A1 – correct calculation of drag area.	C1 M1 A1
(b)(i)	$\tan(\alpha) = \frac{37}{100} \Rightarrow \alpha = 20.304°$	M1
	$F_{slope} = mg\sin\alpha$ $= (85)(9.81)(\sin 20.304^\circ)$ $= 290$ N	M1 A1
(b)(ii)1.	work done against gravity = (mg sin α)(x) = (289)(6.4) = 1850 J	M1 A1
(b)(ii)2.	Since the cyclist and bicycle is moving up the slope at constant speed, $F'_{prop} = F_{air} + F_{slope}$	C1
	From (a), F_{air} = 20 N	
	Hence, P' = F'_{prop} v = (20 N + 289 N) (25 m s^{-1}) = 7 725 W = 7700 W	M1 A1
(c)(i)	By Newton's 2nd Law, $\Sigma\vec{F} = m\vec{a}$ (↑) $N_1 + N_2 = W = mg$ ....(1) (→) $\mu N_1 + \mu N_2 = ma$ ......(2) Hence, $\mu(N_1 + N_2) = \mu mg = ma$	M1 M1

	Solving, $a = \mu g = (0.37)(9.81) = 3.63$ m s^{-2}	**A1**
(c)(ii)	Taking moments about the CG, by principle of moments Sum of anticlockwise moments = Sum of clockwise moments $(43)N_2 + (114)\mu N_1 + (114)\mu N_2 = (107-43)N_1$ $\Rightarrow 43N_2 + 42.18W = 64N_1$ ......(1) Since, $N_1 + N_2 = W$ ……(2) Substituting (2) into (1) and solving, $43(W - N_1) + 42.18W = 64N_1 \Rightarrow N_1 = 0.7960W = 0.80W$ (Shown)	**M1** **M1**
(c)(iii)	Comparing the normal contact force at the front wheel to that at the back wheel, the ratio = 4.	**B1**
(c)(iv)	If the centre of mass moves forward, the (clockwise) torque produced by N_1 decreases and (anticlockwise) N_2 increases. Hence, there is now a net anticlockwise torque on the bicycle causing the bicycle to flip forward.	**B1** **B1**