

Physical Constants and conversion factors

$G = 6.67 \times 10^{-11} \text{ Nm}^2\text{kg}^{-2}$; $g = 9.81 \text{ m/s}^2$; $N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$ $c = 3.00 \times 10^8 \text{ m/s}$;
 $m_e = 9.31 \times 10^{-31} \text{ kg}$; 1 calorie = 4.185 J; $R_E = 6.370 \times 10^6 \text{ m}$; $M_E = 5.98 \times 10^{24} \text{ kg}$;
 $k = 1.38 \times 10^{-23} \text{ J/K}$; $R = 8.314 \text{ J/mol.K}$

Mathematics, Statistics and Geometry

If $ax^2 + bx + c = 0$ then $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$; $\frac{d}{dx}(x^n) = nx^{n-1}$; $\frac{d}{dx}(\sin ax) = a \cos ax$;
 $\frac{d}{dx}(a \cos x) = -a \sin ax$; $\int x^n dx = \frac{x^{n+1}}{n+1} + C$; $\int \sin ax = -\frac{1}{a} \cos ax + C$; $\int \cos ax = \frac{1}{a} \sin ax + C$

$$\vec{a} \cdot \vec{b} = a_x b_x + a_y b_y + a_z b_z = ab \cos \theta; \vec{a} \times \vec{b} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix}; |\vec{a} \times \vec{b}| = ab \sin \theta;$$

Surface area of circle = πr^2 ; Circle Circumf. = $2\pi r$; Volume of sphere = $\frac{4}{3} \pi r^3$;

Area of Sphere = $4\pi r^2$; Binomial Expansion : $(1+x)^n \approx 1+nx$ if $x \ll 1$

$$\sigma_f = \sqrt{\left(\frac{\partial f}{\partial x} \sigma_x\right)^2 + \left(\frac{\partial f}{\partial y} \sigma_y\right)^2 + \left(\frac{\partial f}{\partial z} \sigma_z\right)^2 + \dots}; \sigma = \frac{H-L}{\sqrt{N}}; \sigma_x = \frac{H-L}{N}$$

Physics

$v = \frac{dx}{dt}$; $a = \frac{dv}{dt} = \frac{d^2x}{dt^2}$; $\vec{x} = \vec{x}_0 + \vec{v}_0 t + \frac{1}{2} \vec{a} t^2$; $\vec{v} = \vec{v}_0 + \vec{a} t$; $\vec{v}_{av} = \frac{\vec{v}_0 + \vec{v}}{2}$; $v^2 = v_0^2 + 2a(x - x_0)$;

Arc length = $R\Delta\phi$; $\omega = \frac{d\phi}{dt}$; $v = r\omega$; $\omega = 2\pi f$; $T = \frac{1}{f}$; $a = \frac{v^2}{r} = r\omega^2$; $F = \frac{mv^2}{r} = mr\omega^2$;

$\vec{F}_{net} = m\vec{a}$; friction : $f = \mu F_N$; Hooke's Law : $\vec{F} = -k\vec{x}$; work $W = \vec{F} \cdot \Delta\vec{r}$; $W = \int_{r_A}^{r_B} \vec{F}(\vec{r}) \cdot d\vec{r}$

$K = \frac{1}{2} mv^2$; $U_g = mgy$; $U_E = \frac{1}{2} kx^2$; $E = K + U$; $F = -\frac{dU}{dx}$; $\vec{p} = m\vec{v}$; $\vec{F}_{net} = \frac{d\vec{p}}{dt}$;

$\vec{J} = \Delta\vec{p} = \vec{F}_{av} \Delta t = \int_{t_1}^{t_2} \vec{F}(t) dt$; Centre of Mass : $\vec{R} = \frac{\sum_i m_i \vec{r}_i}{M}$; $X = \frac{1}{M} \int_a^b x \lambda(x) dx$; $M = \int_a^b \lambda(x) dx$;

Moment of Inertia $I = \sum_i m_i r_i^2$; $I = \int_{\text{volume}} \rho(\vec{r}) R^2 dV$; Parallel Axis Theorem: $I_{pa} = I_{cm} + Md^2$;

$\vec{\tau} = I\vec{\alpha} = (\vec{R} \times \vec{F})$; $\vec{L} = I\vec{\omega}$; $\vec{L} = \vec{R} \times \vec{p} = m\vec{R} \times \vec{v}$; $K_{rot} = \frac{1}{2}I\omega^2$; stress $S = \frac{F}{A}$; $e = \frac{\Delta L}{L}$

$\frac{\Delta W}{W} = \frac{\Delta h}{h} = -\sigma e$; $Y = \frac{S}{e}$; $P = \frac{F}{A}$; $\lambda = \frac{M}{L}$; $\sigma = \frac{M}{A}$; $\rho = \frac{M}{V}$;

$\vec{F} = -\left(\frac{GMm}{r^2}\right)\hat{r}$; $U(r) = -\frac{GMm}{r}$; $x(t) = A \sin(\omega t + \delta)$; $x(t) = (A \cos \delta) \sin(\omega t) + (A \sin \delta) \cos(\omega t)$;

$v(t) = \omega A \cos(\omega t + \delta)$; $a = \frac{dv}{dt} = -\omega^2 A \sin(\omega t + \delta) = -\omega^2 x(t)$; $\omega = \sqrt{\frac{k}{m}}$; $E = \frac{1}{2}kA^2$;

$\omega = \sqrt{\frac{g}{l}}$; $\omega = \sqrt{\frac{Mgr}{I}}$; $x(t) = Ae^{-\alpha t} \sin(\omega' t + \delta)$; $T_C = T - 273.15$; $\Delta Q = C\Delta T$;

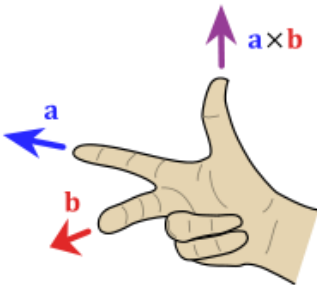
$\Delta Q = cm\Delta T$; $\frac{dQ}{dt} = \kappa A \frac{dT}{dx}$; $R = \frac{L}{\kappa}$; $\frac{\Delta Q}{\Delta t} = \frac{1}{R_{eff}} A\Delta T$; series: $R_{eff} = R_1 + R_2 + \dots$

$PV = NkT = nRT$; $W = \int_{V_1}^{V_2} P dV$; $\Delta U = U_B - U_A = -W_{A \rightarrow B} + Q_{A \rightarrow B}$; $dU = -dW + dQ$;

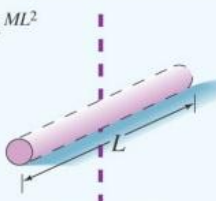


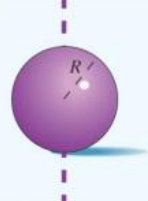
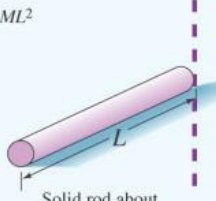

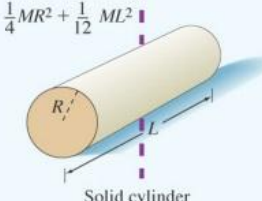

$C_p = C_v + nR$; adiabatic transform: $pV^\gamma = \text{constant}$; $\gamma = \frac{C_p}{C_v}$ $\eta = \frac{W}{Q_h}$; $\eta_c = 1 - \frac{Q_c}{Q_h} = 1 - \frac{T_c}{T_h}$

Heat pump: $COP = \frac{Q_{rej}}{W}$; refrigerator $K_{ref} = \frac{Q_{absorbed}}{W}$; entropy: $S(B) - S(A) = \int_A^B \frac{dQ}{T}$

Clausius' Theorem: $\oint \frac{dQ}{T} \leq 0$ $\Delta t = \gamma \Delta t_p$; $L = \frac{L_p}{\gamma}$; $\vec{p} = \gamma m \vec{u}$; $K = (\gamma - 1)mc^2$; $\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$;



Right Hand Rule

$\frac{1}{12} ML^2$  Solid rod about perpendicular axis through center	MR^2  Cylindrical shell about central axis	$\frac{1}{2} MR^2$  Solid cylinder about central axis	$\frac{2}{5} MR^2$  Solid sphere about any diameter
$\frac{1}{3} ML^2$  Solid rod about perpendicular axis through end	$\frac{1}{2} M(R_1^2 + R_2^2)$  Hollow cylinder about central axis	$\frac{1}{4} MR^2 + \frac{1}{12} ML^2$  Solid cylinder about diameter through center	$\frac{2}{3} MR^2$  Thin spherical shell about any diameter

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Section A: Multiple Choice Questions

Instructions: Please circle your choices on the exam paper.

Q1 What is 0.034 nm, expressed in metres and scientific notation?

(A) 3.4×10^{-11} m	(B) 3.4×10^{-10} m	(C) 3.4×10^{-9} m	(D) 3.4×10^{-8} m	(E) 3.4×10^{-7} m
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Q2 A vector has magnitude 5 and a direction which is 25° counter-clockwise from the positive x-axis. What are the components of the vector?

(A) $5 \cos 25^\circ \hat{i} - 5 \sin 25^\circ \hat{j}$	(B) $5 \cos 25^\circ \hat{i} + 5 \sin 25^\circ \hat{j}$	(C) $-5 \cos 25^\circ \hat{i} + 5 \sin 25^\circ \hat{j}$
(D) $-5 \cos 25^\circ \hat{i} - 5 \sin 25^\circ \hat{j}$	(E) $2.5 \cos 25^\circ \hat{i} + 2.5 \sin 25^\circ \hat{j}$	

Q3 What are the dimensions of Force?

(A) $[MLT^{-1}]$	(B) $[MT^{-2}]$	(C) $[MLT]$	(D) $[MLT^{-2}]$	(E) $[ML^2T^{-2}]$
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Q4 A ball is thrown into the air and performs projectile motion. You may assume that there is no air resistance. Which one of the following statements is **CORRECT**?

- (a) There is always a single solution for the horizontal range, depending on the launch angle θ .
- (b) When the ball reaches the top of the trajectory, the acceleration is zero.
- (c) The ball has a constant x-component of velocity, which depends on the launch angle θ .
- (d) When the ball reaches the top of the trajectory, the velocity is zero.
- (e) The ball has a constant y-component of velocity, which depends on the launch angle θ .

Q5 Calculate the work done when a force $F=(6.0\text{ N})\mathbf{i} - (2.0\text{ N})\mathbf{j} + (2.0\text{ N})\mathbf{k}$ moves an object by a displacement $(-1.0\text{ cm})\mathbf{i} + (1.0\text{ cm})\mathbf{j} + (2.0\text{ cm})\mathbf{k}$.

(A) -0.96 J	(B) -0.056 J	(C) -0.040 J	(D) +0.032 J	(E) +0.084 J
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Q6 A simple pendulum 1.200 m long has a period of $T = 2.196\text{ s}$ when measured in Whitehorse, Yukon. What is the local acceleration due to gravity in Whitehorse?

(A) 9.790 m/s^2	(B) 9.805 m/s^2	(C) 9.8100 m/s^2	(D) 9.824 m/s^2	(E) 9.839 m/s^2
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Q7 In a lab experiment, you measure a mass 5 times with values of 2.135 g, 2.137 g, 2.138 g, 2.138 g and 2.139 g. What is the value of the standard deviation from the mean, calculated using inefficient statistics?

(A) 0.0008 g	(B) 0.0005 g	(C) 0.0010 g	(D) 0.0019 g	(E) 0.0028 g
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Q8 The propeller shafts of the engines of the ship *RMS Titanic* turned at 71 rpm when at cruising speed. The diameter of the propeller is 7.2 m. What is the centripetal acceleration at the outer edge of the propeller?

(A) $2.0 \times 10^2\text{ m/s}^2$	(B) $3.1 \times 10^2\text{ m/s}^2$	(C) $5.4 \times 10^2\text{ m/s}^2$	(D) $7.0 \times 10^2\text{ m/s}^2$	(E) $8.6 \times 10^2\text{ m/s}^2$
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Q9 You use a ruler to make a length measurement. It is marked in centimetres and millimetres. What is the reading error for the ruler?



(A) 1 cm	(B) 0.5 cm	(C) 0.1 cm	(D) 0.5 mm	(E) 0.1 mm
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Q10 You are calculating the value of $F = mg$ from experimental data. Your data has errors in the values of g and m of σ_g and σ_m respectively. Which is the correct expression for the error in F , σ_F ?

(A)	(B)	(C)	(D)	(E)
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Q11 A brick wall has a thickness of 25 cm, and a thermal conductivity $\kappa = 0.63 \text{ W/mK}$. If the temperature of one side of the wall is 25°C and the other side is at -10°C , what is the rate of heat loss over an area of brick wall of 1.0 m^2 ?

(A) 15 W	(B) 21 W	(C) 32 W	(D) 38 W	(E) 88 W
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Q12 An astronaut in a spacecraft flying at $0.67c$ makes a fresh pot of coffee, a process which takes her 5.0 minutes. How long does the process take according to an observer on the earth (stationary with respect to the spacecraft)?

(A) 3.6 minutes	(B) 4.3 minutes	(C) 5.9 minutes	(D) 6.7 minutes	(E) 7.8 minutes
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Q13 A vertical steel wire of diameter 4.0 mm and length 1.7 m has a load of 160.0 kg hung from it. The value of Young's Modulus is $2.0 \times 10^{11} \text{ N/m}^2$. What is the strain on the wire?

(A) 1600 N	(B) 6.2×10^{-4}	(C) 3.2×10^{-4}	(D) 1.1 mm	(E) 0.55 mm
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Q14 The velocity function of an object is: $v(t) = (4.00 \text{ m/s}^3)t^2 - (2.90 \text{ m/s}^4)t^3$

The object starts at $x = 0$ at time $t = 0$. What is its position after 5.00 seconds?

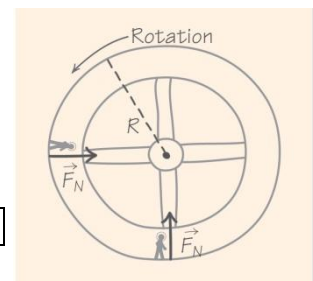
(A) -486 m	(B) -286 m	(C) -51.4 m	(D) 101 m	(E) 394 m
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Q15 Calculate the rotational kinetic energy of the Earth due to the rotation about its own axis, assuming that it is a uniform sphere of radius 6370 km, has a mass of $5.98 \times 10^{24} \text{ kg}$ and an angular speed of $7.3 \times 10^{-5} \text{ rad/s}$

(A) $9.35 \times 10^{28} \text{ J}$	(B) $1.06 \times 10^{29} \text{ J}$	(C) $2.59 \times 10^{29} \text{ J}$	(D) $5.17 \times 10^{29} \text{ J}$	(E) $8.04 \times 10^{29} \text{ J}$
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Q16 For the rotating space station design pictured in the figure, what would the period of rotation have to be in order to provide artificial gravity of the same magnitude as on the Earth? Assume that the radius of the space station is 65 metres

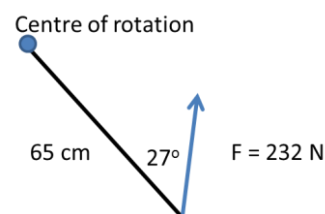
(A) 16 s	(B) 29 s	(C) 84 s	(D) 170 s	(E) 290 s
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Q17 How much energy (in calories) does it take to raise the temperature of 5.00 kg of water from 298K to 318K? The specific heat capacity of water is 1.0 cal/g.°C

(A) 5.0×10^3 cal	(B) 1.0×10^4 cal	(C) 5.0×10^4 cal	(D) 1.0×10^5 cal	(E) 5.0×10^5 cal
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Q18 What is the magnitude of the torque, when a force of 232 N is applied at a distance of 65 cm from the centre of rotation, at an angle of 27°?



(A) 68 N.m	(B) 92 N.m	(C) 110 N.m	(D) 170 N.m	(E) 210 N.m
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Q19 A wind turbine starts at rest, and takes 31 seconds to reach its working angular velocity of $\omega = 1.1$ rad/s. What is the angle (in radians) turned through by the turbine during this time?

(A) π radians	(B) 6.8 radians	(C) 12 radians	(D) 14 radians	(E) 17 radians
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Q20 Temperature differences in the ocean have been proposed as a possible energy source in the tropics. Surface water at 29.0°C could act as a hot reservoir, and deep water at 3.00°C could serve as a cold reservoir. Ammonia gas could be a working fluid in a heat engine that runs between the two thermal reservoirs. What is the maximum efficiency of such an engine?

(A) 6.04%	(B) 7.17%	(C) 8.61%	(D) 9.85%	(E) 10.3%
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Section B: Long Answer Questions

Answer 4 out of the 5 questions in the space under the questions, and use the check boxes on the front page of this exam paper to indicate your choices. ONLY the nominated questions will be marked. If you attempt all 5 questions, you must nominate the 4 questions to be marked. If you fail to make nominations, the first 4 attempted questions will be marked. Show all work, and make clear written statements about which physical principles you are applying. No credit will be given for correct answers without work. Each question is worth 10 marks.

B1 Your eccentric professor is pacing back and forth in a rough approximation to simple harmonic motion. Relative to the centre of the classroom, the motion is between the two extremes $x = +2.5$ m and $x = -2.5$ m. The professor was observed to be at $x = 2.0$ metres at time $t = 4.0$ seconds. The motion was observed to repeat itself 8 times in 100.0 s.

- (a) What are the amplitude, phase, period, and angular frequency of the motion? (5 marks)
- (b) Write the equations of motion $x(t)$, $v(t)$ and $a(t)$ for the oscillating professor. (3 marks)
- (c) What is the maximum speed of the professor? (2 marks)

B2 A sled of mass 110 kg is being pulled across a horizontal ice surface, using a rope which is tilted at 35° with respect to the horizontal and has a tension of 88 N. The coefficient of kinetic friction is 0.030.

- (a) Draw a free body diagram of the forces acting on the sled. (4 marks)
- (b) Find the magnitude and direction of the friction force operating. (3 marks)
- (c) Find the magnitude and direction of the acceleration of the sled. (3 marks)

B3 A standard size compact disk can store 700 Megabytes of data on it. Each binary bit of data is represented by a tiny pit in the surface of the CD. Estimate to the nearest order of magnitude, the surface area per pit. Useful information: 1 byte of information contains 8 bits. To obtain full marks you must explain *in English* any approximations which you use. (10 marks)

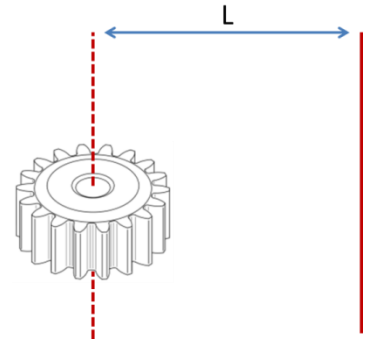
B4 The gear wheel in the figure has a moment of inertia $I = 2.50 \times 10^{-4} \text{ kg}\cdot\text{m}^2$ when rotating about the central (dashed) axis. It has a mass of 0.150 kg. The gear wheel turns about the central axis at a constant angular speed of 1.3 revolutions per minute.

(a) Assuming that it can be approximated to a solid cylinder rotating about the central axis, calculate the radius of the disk. (2 marks)

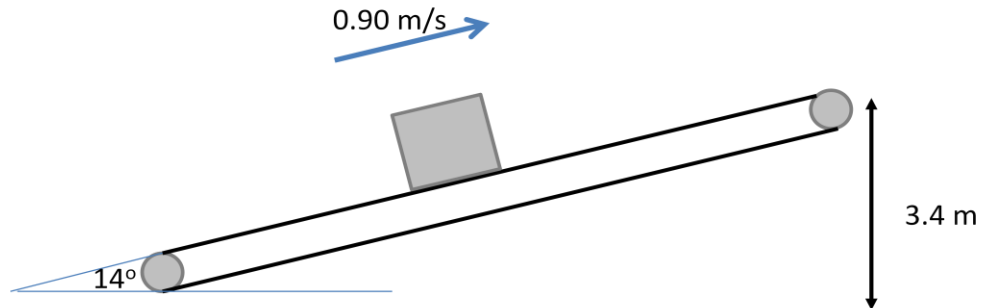
(b) If it rotates about a parallel (solid) axis, which is $L = 24 \text{ cm}$ from the central axis, what is the moment of inertia? (3 marks)

(c) What is the angular momentum of the gear wheel as it turns around the central axis? (3 marks)

(d) If the wheel slows down to rest in 18 seconds, what is the magnitude of the average angular acceleration? (2 marks)



Q5 A conveyor belt is moving crates from ground level to a height of 3.4 m at an angle of 14° to the horizontal. The speed of the conveyor belt is 0.90 m/s. The maximum mass of crates which can be moved on the conveyor belt at the same time is 950 kg. The coefficient of static friction between the crates and the conveyor belt is 0.35.



(a) Draw a free body diagram of the system and calculate the tension T in the conveyor belt. (7 marks)

(b) If the small drive wheels at the ends of the conveyor belt have a radius of 5.0 cm, what angular speed in RPM must they have for the belt to move at 0.90 m/s? (3 marks)