ADRAN FFISEG

Department of Physics

Semester 1
Examinations
January 2026

PH10020 – Dynamics, Waves, and Heat

Time allowed – 3 hours

- Full marks can be attained for complete answers to ALL eight questions in Section A and TWO questions from Section B.
- The numbers in brackets after the questions indicate the allocation of marks for each question.
- Only calculators from the Casio FX83, FX85 or FX991 range may be used.
- A booklet of mathematical formulae and standard constants will be provided.
- Mae modd i fyfyrwyr gyflwyno atebion i'r papur hwn naill ai yn y Gymraeg neu'r Saesneg.
- Students may submit answers to this paper in either Welsh or English.

Once seated, students may complete the front cover of the answer book(s) and the attendance slip ONLY.

DO NOT TURN THE EXAMINATION QUESTION PAPER OVER UNTIL INSTRUCTED TO DO SO.

Newtonian Mechanics:

$\mathbf{F} = m\mathbf{a}$

$\Delta E_{\text{pot}} + \Delta E_{\text{tr}} + \Delta E_{\text{rot}} = 0$

SHO:

$a + \omega^2 x = 0$

$x = A\cos(\omega t + \phi)$

$v_{\max} = \omega A$

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

Pendulum Motion:

$\vartheta = \vartheta_{\max}\cos\left(2\pi\dfrac{t}{T} + \varphi\right)$

$T = 2\pi\sqrt{\dfrac{I}{2MD}}$

Under-damped Oscillation:

$\tau = \dfrac{2m}{b}$

$x = A(t)\cos(\omega t + \Phi)$

$A(t) = A\exp\left(-\dfrac{t}{\tau}\right)$

Rotation:

$\omega = \dfrac{d\vartheta}{dt} \qquad \alpha = \dfrac{d\omega}{dt}$

$v = r\omega \qquad a = r\sqrt{\alpha^2 + \omega^4}$

$\Delta\alpha = 0$: $\omega = \omega_0 + \alpha t$

$I_{\text{cm rod}} = \dfrac{1}{12}ML^2$

$k_{\text{cm sphere}} = \dfrac{2}{5}MR^2$

$I = I_{\text{CM}} + MD^2$

$I = I_1 + I_2 + \cdots$

$x_{\text{cm}} = \dfrac{m_1 x_1 + m_2 x_2 + \cdots}{m_1 + m_2 + \cdots}$

$L = I\omega$

$\tau_{\text{net}} = \sum_{i=1}^{n} \pm F_i d_i$

$\boldsymbol{\tau}_{\text{net}} = I\boldsymbol{\alpha}$

Calorimetry:

$c_{\text{A}} m_{\text{A}}(T_{\text{A f}} - T_{\text{A i}})$

$\quad + c_{\text{B}} m_{\text{B}}(T_{\text{B f}} - T_{\text{B i}}) = 0$

Ideal Gas:

$PV = nRT$

$\Delta U_{\text{AB}} = C_V(T_{\text{B}} - T_{\text{A}})$

$W_{\text{AB}} = -\int_{V_{\text{A}}}^{V_{\text{B}}} P\,dV$

$\Delta U = W + Q$

$\left(W \equiv W_{[\text{on the gas}]}\right)$

$\Delta P = 0$:

$Q_{\text{AB}} = C_P(T_{\text{B}} - T_{\text{A}})$

$W_{\text{AB}} = -P(V_{\text{B}} - V_{\text{A}})$

$\Delta V = 0$:

$Q_{\text{AB}} = C_V(T_{\text{B}} - T_{\text{A}})$

$\Delta T = 0$:

$Q_{\text{AB}} = nRT\ln\left(\dfrac{V_{\text{B}}}{V_{\text{A}}}\right)$

$W_{\text{AB}} = -nRT\ln\left(\dfrac{V_{\text{B}}}{V_{\text{A}}}\right)$

Maxwell-Boltzmann Distribution:

$v_{\text{mp}} = \sqrt{\dfrac{2RT}{M}}$

$v_{\text{rms}} = \sqrt{\dfrac{3RT}{M}}$

$v_{\text{av}} = \sqrt{\dfrac{8RT}{\pi M}}$

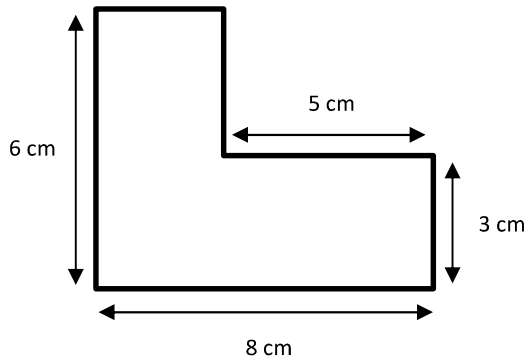
$M = \dfrac{m}{n}$

Section A

Attempt ALL the eight questions.

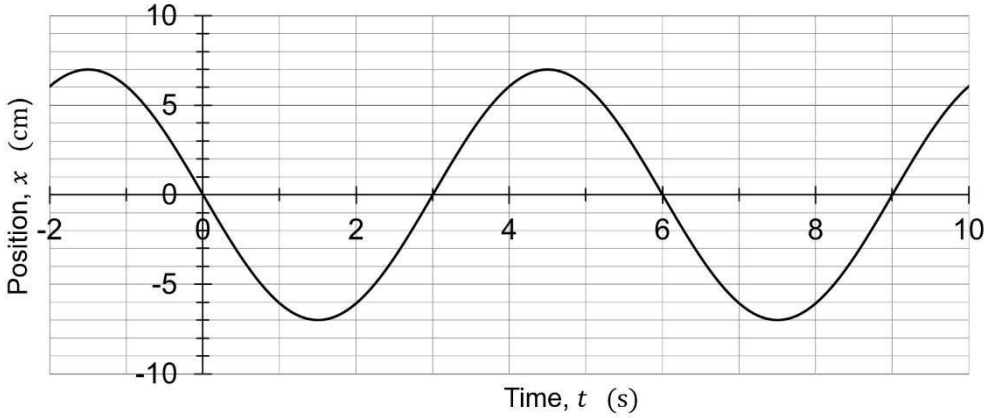
1 A 30kg object moves in the direction of a $\boldsymbol{r} = (3\boldsymbol{i} + 2t^2\boldsymbol{j} + 6t\boldsymbol{k})$ m displacement vector. Determine the magnitude of the object's momentum at time $t = 2s$. [5]

2 A block of wood of uniform thickness is worked into the shape shown below: [5]



Determine the object's centre of mass.
Let the origin of the (x, y) coordinate system be at the bottom left corner of the object.

3 The position, x, of a small object undertaking simple harmonic oscillation is plotted against time, t. [5]



Determine the acceleration of the object at $t = 14$ s.

4 The damping coefficient of a force acting on an under-damped oscillator of mass $m = 300\ \mathrm{g}$ is: $b = 20\ \mathrm{g\ s^{-1}}$. [5]

At time $t_1 = 10\ \mathrm{s}$, the oscillation amplitude is: $A_1 = 0.8\ \mathrm{m}$

Derive the amplitude, A_2, of the oscillation at time $t_2 = 20\ \mathrm{s}$.

5 An object is rotating about a fixed rotational axis with constant angular deceleration, $\alpha = -0.1\ \mathrm{rad\ s^{-2}}$, until it stops. The moment of inertia of the object for its rotational axis is: $I = 6.5\ \mathrm{kg\ m^2}$ [5]

At time $t = 0$, the angular momentum of the object is: $L_0 = 3.9\ \mathrm{J\ s}$

Find the time when the object will get to a halt: $\omega = 0$

6 A ball is rolling down a slope with a constant tilt angle.

a) Give a list of the main forces, which altogether accelerate the centre of mass of the ball. [3]

b) Describe the torque of each of the forces. [2]

7 The side of an aluminium cube is $a = 0.1\ \mathrm{m}$ long. [5]

The initial temperature of water in a tank is: $T_\mathrm{w} = 30\ ^\circ\mathrm{C}$

How much water, m_w, is in the tank if, by immersing the cube into it, it cools from $T_{\mathrm{Al}\,1} = 55\ ^\circ\mathrm{C}$ to $T_{\mathrm{Al}\,2} = 35\ ^\circ\mathrm{C}$?

It can be assumed that the heat lost to the environment of the water-aluminium system is negligible.

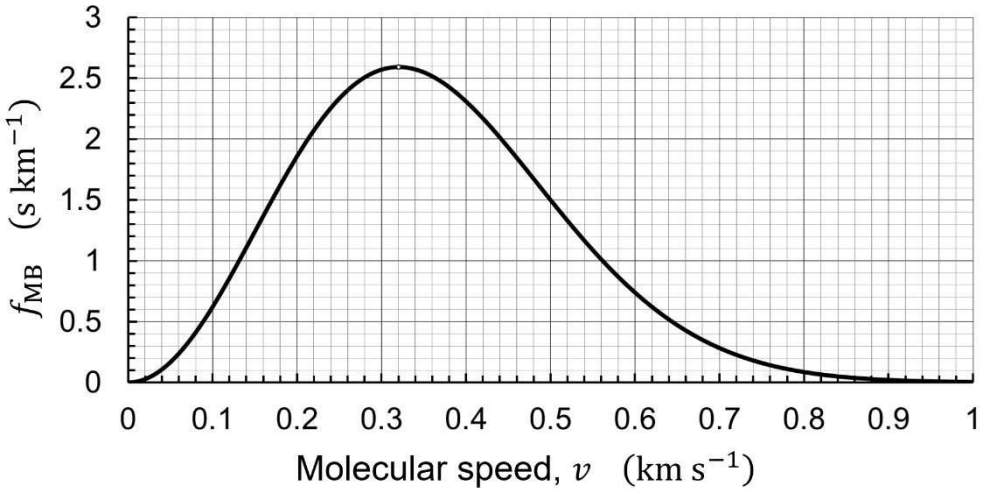
The aluminium density and the specific heat capacities of aluminium and water, respectively, are:

$\rho_\mathrm{Al} = 280\ \mathrm{kg\ m^{-3}}$ $\quad c_\mathrm{Al} = 900\ \mathrm{J\ kg^{-1}\ K^{-1}}$ $\quad c_\mathrm{w} = 4200\ \mathrm{J\ kg^{-1}\ K^{-1}}$

8 The pressure of an ideal gas in a tank is: $P = 160\ \text{kPa}$ [5]

The volume of the tank is: $V = 0.8\ \text{m}^3$

The Maxwell-Boltzmann velocity distribution function of the gas is shown below.



Find the mass of the gas.

Section B

Answer TWO of the three questions.

9 A coal train consists of a 5000 kg locomotive and three 500 kg carts. The train accelerates from rest to a constant speed of 80 $\mathrm{m\ s^{-1}}$ in 200 seconds.

a) Assuming constant acceleration, determine the acceleration of the train and the force of the locomotive's engine.

[5]

b) Determine the train's momentum once it has reached constant speed.

[3]

Sometime later, the train (train A) crashes into an oncoming train (train B) that is travelling in the opposite direction at 79.9 $\mathrm{m\ s^{-1}}$. Train B is 100 kg lighter than train A. The trains collide and lock together to form a 50m-long slowly moving wreckage.

c) Determine the momentum of the wreckage immediately after the collision.

[5]

During the collision, a 400 kg bag of coal is launched from the wreckage in the direction of motion of train A at an angle of $30°$ from the horizontal tracks with an initial speed of $21.6\ \mathrm{m\ s^{-1}}$. Ignore air resistance.

d) Determine the maximum height reached by the bag of coal.

[3]

e) Determine the time it takes the coal to reach its maximum height and then return to its original elevation.

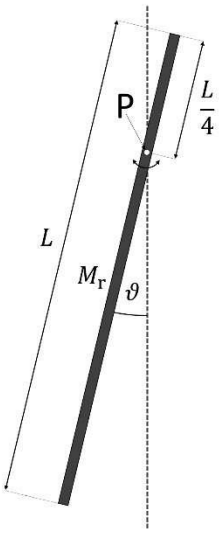
[2]

The bag of coal is ejected from the centre of the middle cart of train A, located 10 m from the back of the wreckage.

f) Determine whether the launched bag of coal lands ahead of the wreckage or on top of it.

[2]

10 A thin uniform rod of mass $M_\mathrm{r} = 0.5\ \mathrm{kg}$ and length $L = 0.8\ \mathrm{m}$ is pivoted through a small hole halfway between one of the ends and the middle point of the rod. The rod can rotate about the horizontal rotational axis that goes through pivot point P.



a) Work out the moment of inertia, I, of the rod for the horizontal rotational axis through pivot point P.

[5]

b) The rod is released from rest at angular position $\vartheta_\mathrm{max} = 12°$ and undergoes pendulum motion.

i) Calculate the period, T, of the pendulum motion of the rod.

[3]

ii) Find the maximum angular speed, ω_max, of the rod.

[3]

iii) Give the range of the angular momentum, L, of the rod during its pendulum motion.

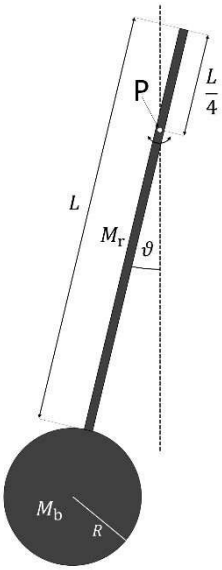
[2]

iv) Determine the speed, v, of the bottom end of the rod when the rod is vertical.

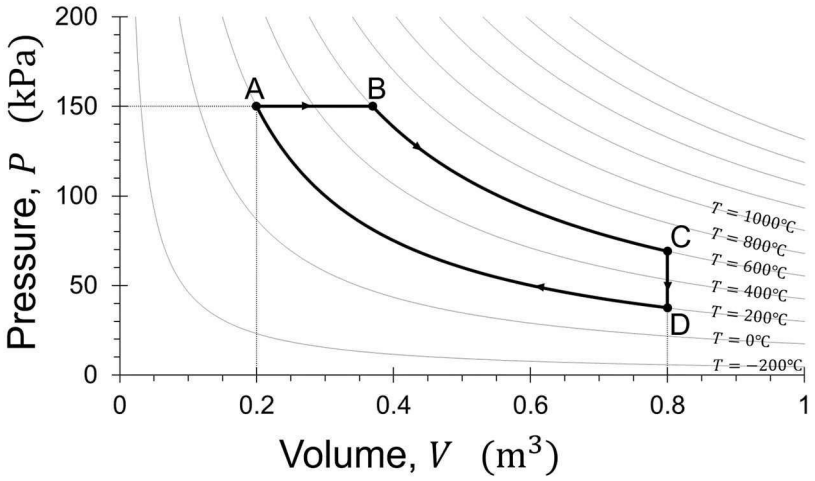
[2]

c) How does the period of the pendulum motion change when a uniform ball of mass $M_\mathrm{b} = 0.5\ \mathrm{kg}$ and radius $R = 0.2\ \mathrm{m}$ is attached to the bottom end of the rod?

[5]



11 Nitrogen gas, N_2, goes through the four-step thermodynamic loop ABCDA, as shown in the PV diagram.



a) Reading the state variables at state A from the diagram, determine the mole number, n, of the gas.

[2]

b) Considering that N_2 is a diatomic gas, give the:

i) Constant-volume heat capacity, C_V, and

ii) Constant-pressure heat capacity, C_P, of the gas

[4]

c) Determine the gas volume, V_B, at state B.

[2]

d) Work out the gas pressure at states C and D.

[4]

e) Find the following quantities during each of the four processes:

i) Work done on the gas: W_AB, W_BC, W_CD, and W_DA

[2]

ii) Change in the internal energy of the gas: ΔU_AB, , ΔU_BC, ΔU_CD, and ΔU_DA

[2]

iii) Heat added to the gas: Q_AB, , Q_BC, Q_CD, and Q_DA

[2]

f) Using the results of question (e) for any of the four steps (AB, BC, CD, or DA) of the loop, verify the first law of thermodynamics.

[2]

END OF PAPER