PRIFYSGOL ABERYSTWYTH UNIVERSITY

Entrance Examination
February 2024

Physics

Time allowed: 1.5 hours (90 minutes)

This examination paper consists of a data analysis exercise and seven questions. Try to attempt all. Please indicate each question number at the beginning of your working and highlight your final numerical answers (including units) by, for example, underlining or framing.

Marks will be awarded for correct approaches, thoughts, ideas, or methods, even if the final answer is missing or incorrect. No negative marks will be awarded for inaccurate or faulty arguments or incorrect answers.

Feel free to use any standard booklets of fundamental constants and/or formulas, provided by your school or the short list of constants and formulas below.

Any calculators are allowed to be used.

Approximate values of a few Fundamental Constants

Electron charge	$e = 1.60 \times 10^{-19}\ \mathrm{C}$
Electron mass	$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
Gravitational constant	$G = 6.67 \times 10^{-11}\ \mathrm{m^3\ kg^{-1}\ s^{-2}}$
Planck's constant	$h = 6.63 \times 10^{-34}\ \mathrm{m^2\ kg\ s^{-1}}$
Speed of light	$c = 3.00 \times 10^{8}\ \mathrm{m\ s^{-1}}$
Gas constant	$R = 8.31\ \mathrm{J\ K^{-1}\ mol^{-1}}$

Further Useful Constants

Gravitational acceleration	$g = 9.8\ \mathrm{m\ s^{-2}}$
Mass of an alpha particle	$m_\alpha = 6.64 \times 10^{-27}\ \mathrm{kg}$
Boltzmann constant	$k_\mathrm{B} = 1.38 \times 10^{-23}\ \mathrm{J\ K^{-1}}$
Astronomical unit	$1\ \mathrm{AU} = 1.5 \times 10^{11}\ \mathrm{m}$
Ångström	$1\ \mathrm{Å} = 10^{-10}\ \mathrm{m}$
Electronvolt	$1\ \mathrm{eV} = 1.6 \times 10^{-19}\ \mathrm{J}$
Avogadro number	$N_\mathrm{A} = 6.22 \times 10^{23}\ \mathrm{mol^{-1}}$
Temperature conversion	$T_\mathrm{K} - T_{^\circ\mathrm{C}} = 273.15$

Formulas

$PV = Nk_\mathrm{B}T$ $\quad PV = nRT$ $\quad n = \frac{N}{N_\mathrm{A}}$ $\quad M = \frac{m}{n}$

$\Delta U = Q_\text{to gas} - W_\text{by gas}$ $\quad \Delta U = cm\Delta T$ $\quad W_\text{by gas} = P\Delta V$

$v \equiv \frac{dx}{dt}$ $\quad a \equiv \frac{dv}{dt}$ $\quad \omega = \frac{2\pi}{T}$

$s = s_0 + ut + \frac{1}{2}at^2$ $\quad v = u + at$ $\quad a_n = \frac{v^2}{r}$

$y = u_y t - \frac{1}{2}gt^2$ $\quad x = u_x t$

$\tau = Fd$ $\quad \tau = I\alpha$ $\quad L = I\omega$ $\quad E_\mathrm{rot} = \frac{1}{2}I\omega^2$

$E_\mathrm{kin} = \frac{1}{2}mv^2 = \frac{p^2}{2m}$ $\quad E_\mathrm{pot} = -\frac{GMm}{r}$ $\quad E_\mathrm{pot} = mgh$

$F_\mathrm{e} = k\frac{qQ}{r^2}$ $\quad F_\mathrm{gr} = \frac{GMm}{r^2}$ $\quad \vec{\boldsymbol{r}}_\mathrm{cm} = \frac{\sum m_i \vec{\boldsymbol{r}}_i}{\sum m_i}$

$E = hf$ $\quad c = \lambda f$ $\quad \lambda_0 = 2L$ $\quad \lambda_\mathrm{B} = \frac{h}{p}$ $\quad N = N_0\, 2^{-\frac{t}{T_{1/2}}}$

$F = PA$ $\quad E = mc^2$ $\quad g = \frac{GM}{r^2}$ $\quad \rho = \frac{m}{V}$ $\quad A = \pi r^2$

$V = IR$ $\quad q = CV$ $\quad E_J = Vq$ $\quad q = It$ $\quad q = Ne$

$P = IV = I^2R = \frac{V^2}{R}$ $\quad \sum I_i = 0$ $\quad \sum V_i = 0$ $\quad c = \frac{c_\text{vacuum}}{n}$

$\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$ $\quad M = \frac{i}{o}$ $\quad n_1 \sin\ \alpha_1 = n_2 \sin \alpha_2$

$$N_\mathrm{n} m_\mathrm{n} c^2 + N_\mathrm{p} m_\mathrm{p} c^2 = m_\text{nucleus} c^2 + U_\text{binding}$$

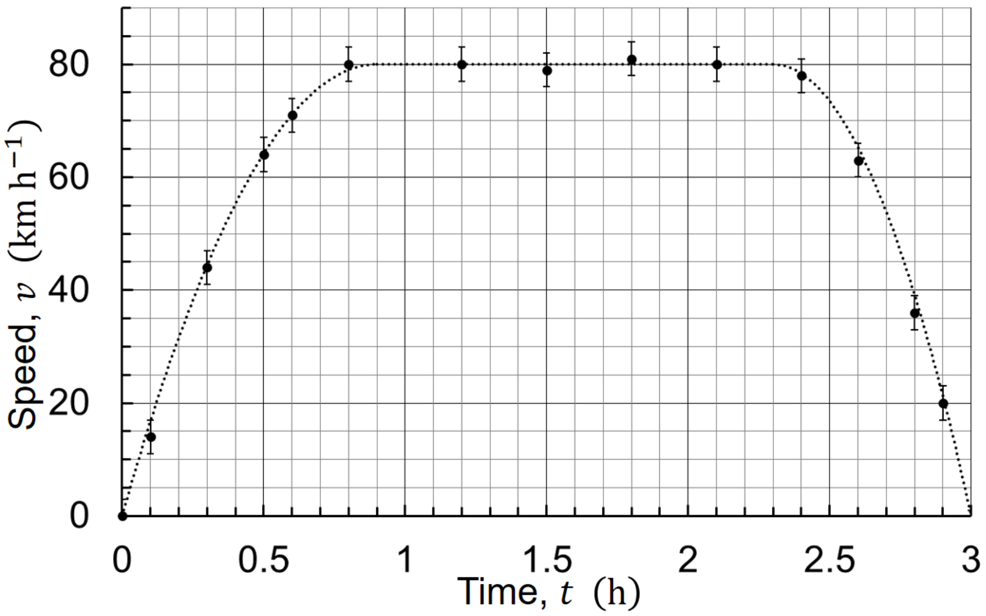
Section A

Data Analysis Exercise [12 points]

A car of mass $= 2500\ \mathrm{kg}$ moves from town A to town B. The speed of the car is recorded during its journey thirteen times:

Time:	Speed:
$t_1 = 6\ \mathrm{min}$	$v_1 = 14\ \mathrm{km\ h^{-1}}$
$t_2 = 18\ \mathrm{min}$	$v_2 = 44\ \mathrm{km\ h^{-1}}$
$t_3 = 30\ \mathrm{min}$	$v_3 = 64\ \mathrm{km\ h^{-1}}$
$t_4 = 36\ \mathrm{min}$	$v_4 = 71\ \mathrm{km\ h^{-1}}$
$t_5 = 48\ \mathrm{min}$	$v_5 = 80\ \mathrm{km\ h^{-1}}$
$t_6 = 72\ \mathrm{min}$	$v_6 = 80\ \mathrm{km\ h^{-1}}$
$t_7 = 90\ \mathrm{min}$	$v_7 = 79\ \mathrm{km\ h^{-1}}$
$t_8 = 108\ \mathrm{min}$	$v_8 = 81\ \mathrm{km\ h^{-1}}$
$t_9 = 126\ \mathrm{min}$	$v_9 = 80\ \mathrm{km\ h^{-1}}$
$t_{10} = 144\ \mathrm{min}$	$v_{10} = 78\ \mathrm{km\ h^{-1}}$
$t_{11} = 156\ \mathrm{min}$	$v_{11} = 63\ \mathrm{km\ h^{-1}}$
$t_{12} = 168\ \mathrm{min}$	$v_{12} = 36\ \mathrm{km\ h^{-1}}$
$t_{13} = 174\ \mathrm{min}$	$v_{13} = 20\ \mathrm{km\ h^{-1}}$

The data points are plotted below in the speed-against-time diagram with error bars, indicating a $\pm 5\ \mathrm{km\ h^{-1}}$ uncertainty on the measured speeds. The dotted line is the graph of function $v(t)$ which is the best fit to the recorded data.



a) Find the average acceleration between times t_1 and t_2.

b) Work out the change in the kinetic energy between times t_9 and t_{12}.

c) Give the maximum momentum of the car during the journey.

d) Using the plotted data, estimate the distance between town A and town B.

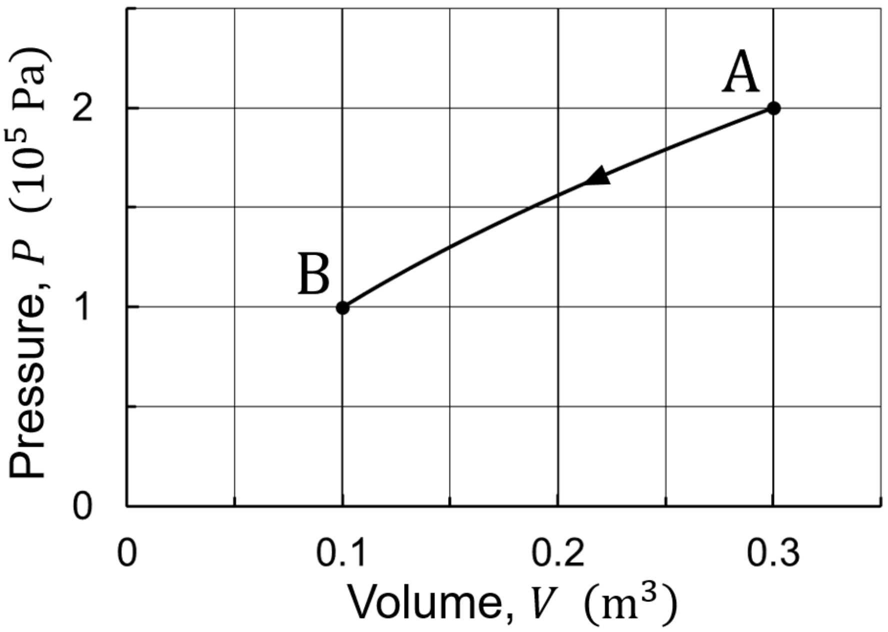
Section B

Question 1 [5 points]

On a smooth horizontal surface, blocks A and B are moving towards each other at the same speed: $u_{\mathrm{A}} = 1\ \mathrm{m\ s^{-1}}$ and $u_{\mathrm{B}} = -1\ \mathrm{m\ s^{-1}}$. Due to an elastic heads-on collision, block A stops. At what speed is block B going away from the collision? Based on the collision, can we find out anything about the masses of the two blocks?

Question 2 [5 points]

The PV (pressure against volume) diagram below shows the thermodynamic process of an ideal (or perfect) gas of mole number $n = 200\ \mathrm{mol}$ as it is compressed to the third of its original volume while its pressure halves. Work out the change in the gas temperature during the process A to B.



Question 3 [5 points]

In a mixture of radiative materials A and B, their ratio initially, at $t = 0$, is: $A\!:\!B = 1\!:\!2$

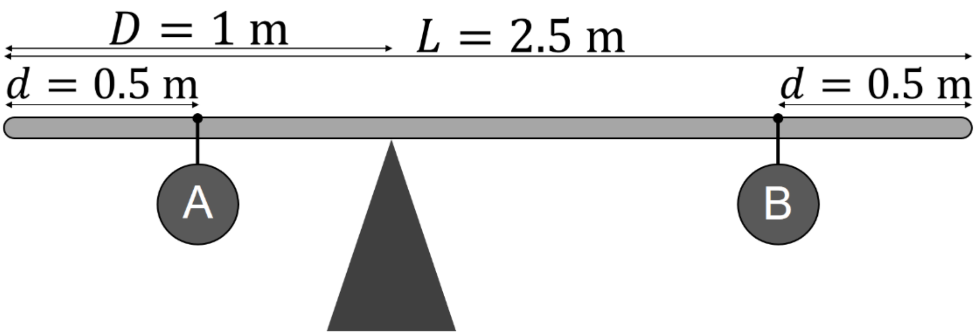
The half-life of material A is $T_\mathrm{A} = 2\ \mathrm{day}$, and the half-life of material B is $T_\mathrm{B} = 1\ \mathrm{day}$.

Find the time when the ratio of the two materials in the mixture will be: $A\!:\!B = 2\!:\!1$

Question 4 [5 points]

An $L = 2.5\ \mathrm{m}$ long log is balanced on a pivot at distance $D = 1.0\ \mathrm{m}$ from one of the ends of the log.

Object A with mass $m_\mathrm{A} = 3.0\ \mathrm{kg}$ and object B with mass $m_\mathrm{B} = 1.0\ \mathrm{kg}$ are hanging from the log, each at $d = 0.5\ \mathrm{m}$ distance away from one end of the log, as shown in the illustration, and the two objects are in balance on the log.



When we double the mass of object B, how should we change the mass of object A to keep the balance?

Question 5 [5 points]

We drop two ice cubes of temperature $T_{\mathrm{i0}} = -3\ °\mathrm{C}$ into a glass of apple juice.

Using the below data, and assuming no heat exchange between the juice and its environment (air or the glass), predict the juice temperature once the ice cubes have melted in it.

Volume of an ice cube: $V_\mathrm{i} = 1\ \mathrm{cm}^3\ (= 10^{-6}\ \mathrm{m}^3)$

Density of the ice cubes: $\rho_\mathrm{i} = 900\ \mathrm{kg\ m}^{-3}$

Specific heat capacity of ice: $c_\mathrm{i} = 2100\ \mathrm{J\ kg}^{-1}\ °\mathrm{C}^{-1}$

Latent heat of ice: $L_\mathrm{i} = 335\ \mathrm{J\ g}^{-1}\ °\mathrm{C}^{-1}$

Volume of the juice in the glass: $V_\mathrm{j} = 2\ \mathrm{dl}\ (= 2 \times 10^{-4}\ \mathrm{m}^3)$

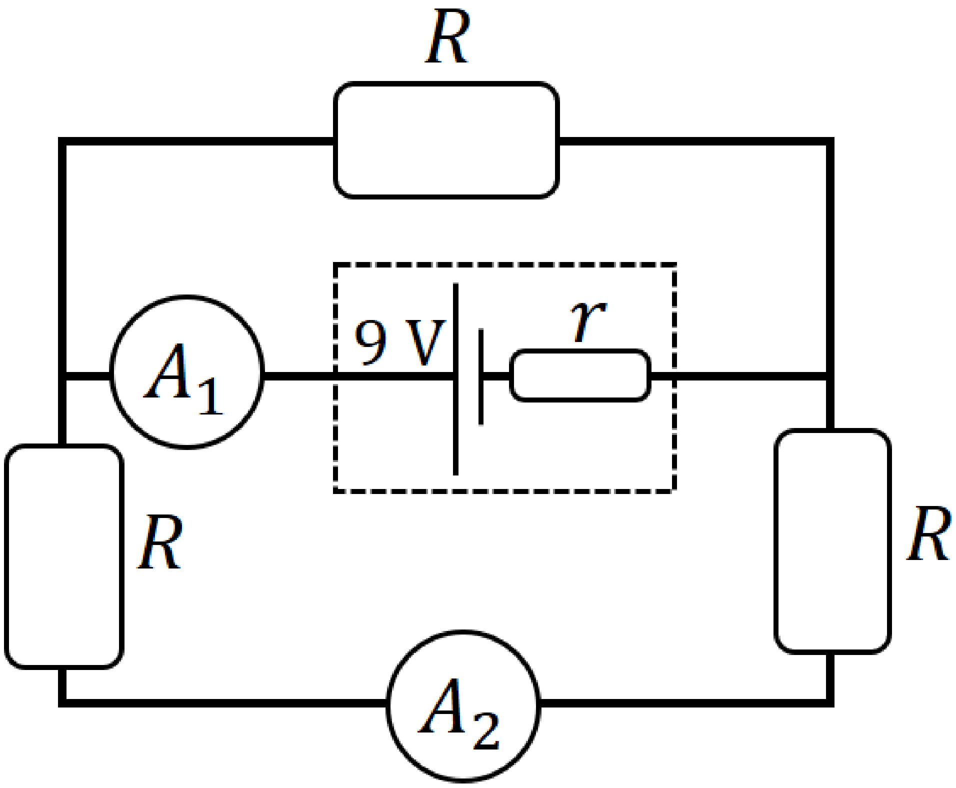
Density of the juice: $\rho_\mathrm{j} = \rho_\mathrm{water} \approx 1\ \mathrm{kg\ l}^{-1}\ (= 10^3\ \mathrm{kg\ m}^{-3})$

Temperature of the juice: $T_{j0} = 17\ °C$

Specific heat capacity of the juice: $c_j = c_{water} = 4200\ J\ kg^{-1}\ °C^{-1}$

Question 6 [5 points]

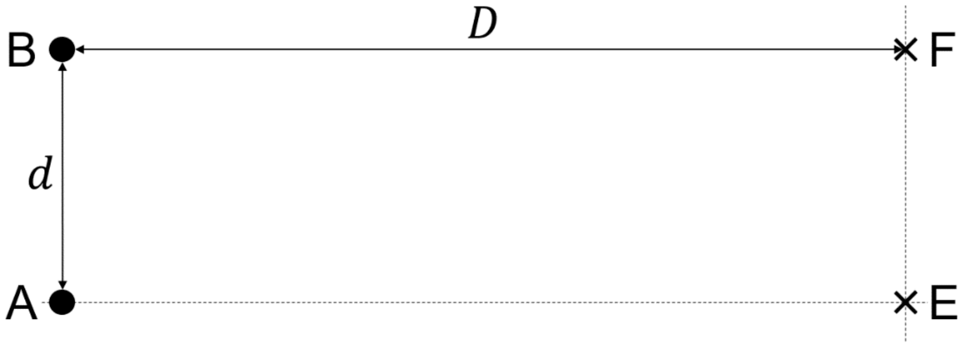
In the below circuit, the current delivered by the cell of emf $9\ V$ and internal resistance r and read by ammeter A_1 is $1.5\ A$ larger than the current read by ammeter A_2. The resistance of each of the three resistors is $R = 4.5\ \Omega$.



Determine the value of the internal resistance, r.

Question 7 [5 points]

Loudspeakers A and B are at distance $d = 1.5\ \mathrm{m}$ from each other.



They are connected to a signal generator that produces a signal at a frequency of $f = 1041\ \mathrm{Hz}$. Positions E and F are at distance $D = 5\ \mathrm{m}$ away from loudspeakers A and B, respectively. Find out whether an observer at position E or F could hear a quiet or loud signal as a result of the superposition of the sound waves coming from the two loudspeakers. The sound speed there is: $c = 331\ \mathrm{m\ s^{-1}}$