PRIFYSGOL ABERYSTWYTH UNIVERSITY

ENTRANCE SCHOLARSHIP EXAMINATION 2023

PHYSICS

Time Allowed – 1.5 hours

This examination paper consists of a data analysis exercise and six 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	$e = 1.60 \times 10^{-19}$ C
Electron mass	$m_e = 9.11 \times 10^{-31}$ kg
Gravitational constant	$G = 6.67 \times 10^{-11}$ m^3 kg^{-1} s^{-2}
Planck's constant	$h = 6.63 \times 10^{-34}$ m^2 kg s^{-1}
Speed of light	$c = 3.00 \times 10^8$ m s^{-1}
Gas constant	$R = 8.31$ J K^{-1} mol^{-1}

Further Useful Constants

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

Formulas

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

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

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

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

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

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

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

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

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

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

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

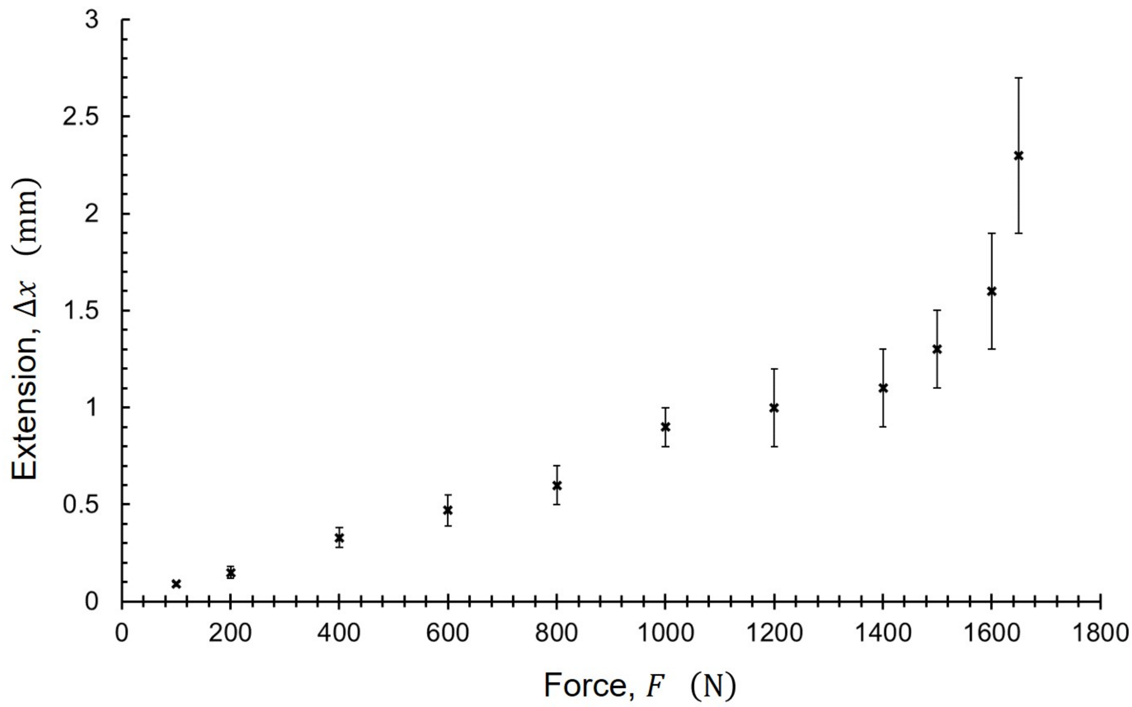
$\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$ $\quad M = \frac{i}{o}$ $\quad n_1 \sin\ \alpha_1 = n_2 \sin \alpha_2$

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

Data Analysis Exercise

An $L = 2.3$ m long wire with cross-sectional area $A = 5 \times 10^{-8}$ m^2 is stretched by eleven different weights. The resulting extensions are listed in the table below. The experimental data set is also visualised by the extension-force plot.

Force F (N)	Extension Δx (mm)
100	0.09 ± 0.01
200	0.15 ± 0.03
400	0.33 ± 0.05
600	0.47 ± 0.08
800	0.6 ± 0.1
1000	0.9 ± 0.1
1200	1.0 ± 0.2
1400	1.1 ± 0.2
1500	1.3 ± 0.2
1600	1.6 ± 0.3
1650	2.3 ± 0.4



a) For not too strong forces, the wire behaves elastically: the wire takes back its original shape and size when the force is removed.

Using Hooke's law, $\boldsymbol{F} = -k\boldsymbol{\Delta x}$, find the stiffness (or spring constant), k, of the wire.

b) The material's Young modulus of elasticity is:

$$E = \frac{\sigma}{\varepsilon}$$

Here ε is the strain – the ratio between the extension, Δx, of an object caused by a force, and the original length, L, of the object:

$$\varepsilon = \frac{\Delta x}{L}$$

And σ is the stress – the ratio between the force, F, acting on the object and the cross-sectional area, A, of the object:

$$\sigma = \frac{F}{A}$$

Using the measured data, derive a value for the Young modulus of the wire.

c) Based on the value derived for the Young modulus, which material is the wire most likely made of ?

Aluminium: $E_{\mathrm{Al}} = 69\ \mathrm{GPa}$

Copper: $E_{\mathrm{Cu}} = 117\ \mathrm{GPa}$

Platinum: $E_{\mathrm{Pt}} = 147\ \mathrm{GPa}$

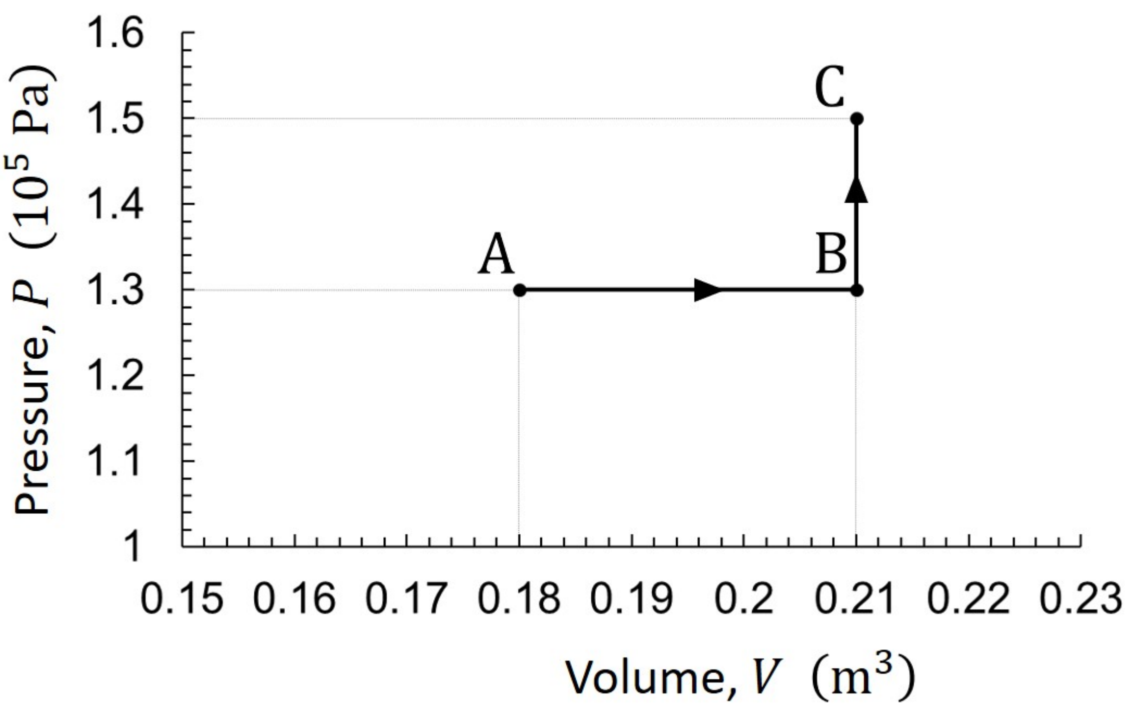
Zinc: $E_{\mathrm{Zn}} = 83\ \mathrm{GPa}$

d) What does the extension-force data set indicate about the behaviour of the wire when strong forces are applied on it?

Question 1

$n = 9.0 \text{ mol}$ of an ideal gas in a sealed container undergoes a thermodynamic process that takes it from state A to state C through state B as shown in the PV diagram.

Determine a) the work done by the gas and b) the change in the gas temperature during the two-step process.



Question 2

Fusion of deuterium and tritium creates an alpha particle while freeing a neutron and releasing energy:

$${}_{1}^{2}\mathrm{H} + {}_{1}^{3}\mathrm{H} = {}_{2}^{4}\mathrm{He} + {}_{0}^{1}\mathrm{n}$$

Calculate the energy, in MeV, released during the above reaction.

The masses of the particles are:

$$m_{{}_{1}^{2}\mathrm{H}} = 2.0141\ \mathrm{u}$$

$$m_{{}_{1}^{3}\mathrm{H}} = 3.0160\ \mathrm{u}$$

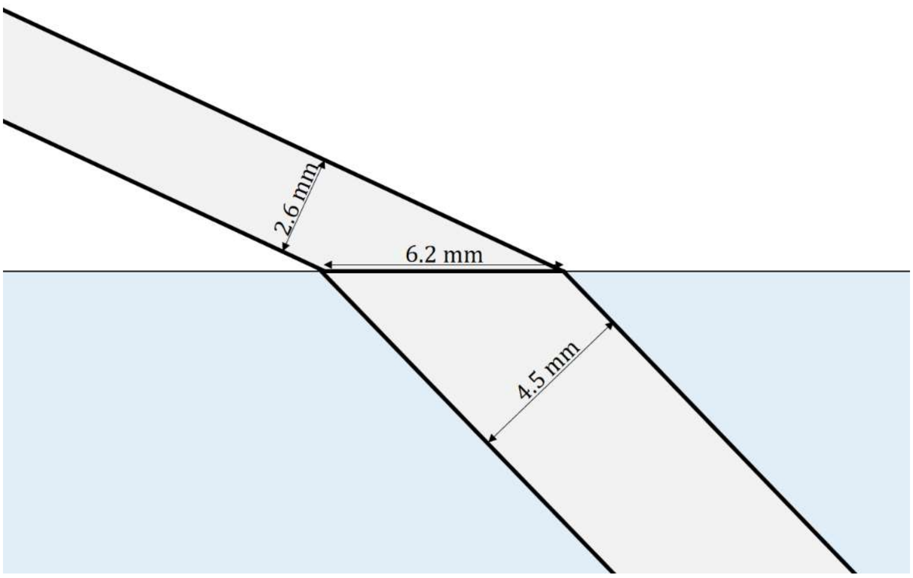
$$m_{{}_{2}^{4}\mathrm{He}} = 4.0025\ \mathrm{u}$$

$$m_{{}_{0}^{1}\mathrm{n}} = 1.0087\ \mathrm{u}$$

The atomic mass unit is: $1\ \mathrm{u} = 931\ \mathrm{MeV}$

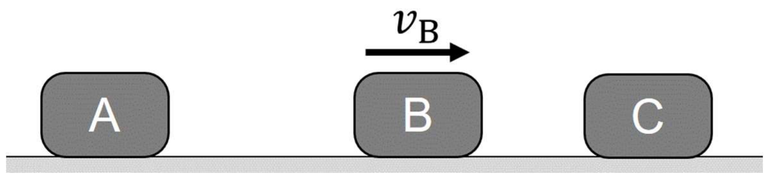
Question 3

A light beam of width $d_1 = 2.6\ \mathrm{mm}$ passes from air into water, creating a bright oval spot with major axis $d = 6.2\ \mathrm{mm}$ on the water surface. The width of the light beam in the water is $d_2 = 4.5\ \mathrm{mm}$. Calculate the refractive index of the water.



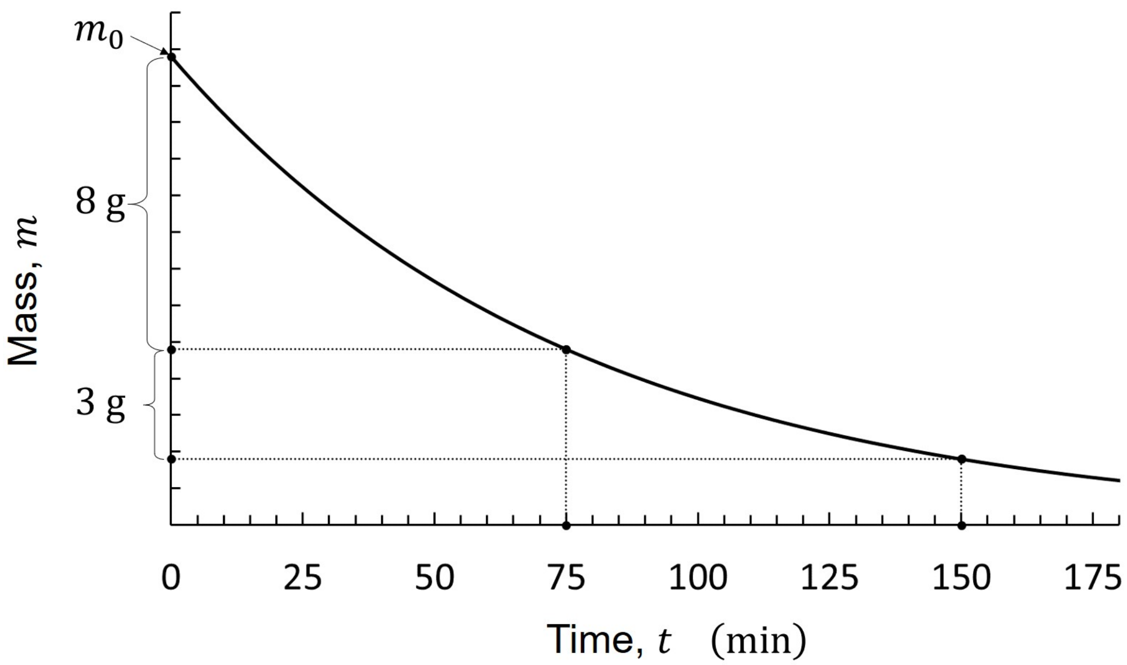
Question 4

Three blocks, A, B, and C, of masses $m_A = 100$ g, $m_B = 300$ g, and $m_C = 700$ g, respectively, are aligned on a horizontal smooth surface. Initially, block B is moving away from A and towards C at speed $v_B = 0.5\ \mathrm{m\ s^{-1}}$, while blocks A and C are at rest. Assuming that the blocks collide elastically, find the speeds of the blocks after their collisions.



Question 5

8 g of a radioactive material with initial mass m_0 decayed in 75 minutes. Another 75-minute time later, the mass of the material was found further 3 g less than previously. Find a) the original mass, m_0, and b) the half-life, $T_{1/2}$, of the material.



Question 6

The time between consecutive sunsets on Jupiter is about ten hours. The distance between Jupiter and Europa, one of Jupiter's moons, is $d \approx 670\ 000\ \mathrm{km}$. It takes about $t = 85\ \mathrm{h}$ for Europa to go around Jupiter. According to Kepler's third law of planetary motion, the ratio between the cube of the orbital period of objects orbiting a planet and the square of the orbital distance is determined by the mass of the planet only, that is, the ratio $\frac{d^3}{T^2}$ is constant.

Using the above information, work out how far from the centre of Jupiter a stationary satellite above Jupiter's equator should be. (A satellite orbiting a planet is stationary if it stays above the same position of the planet.)