PRIFYSGOL ABERYSTWYTH UNIVERSITY 1872

ENTRANCE SCHOLARSHIP EXAMINATION
JANUARY 2019

PHYSICS

Time Allowed – 1.5 hours

This examination paper consists of two sections, A and B. Both sections are composed of seven questions. All the questions from Section A and at least six questions from Section B should be attempted. (If you attempt all the seven questions in Section B, the best six will contribute to your mark.)

Use the notebook(s) provided to work out your solutions.

Please clearly indicate each question number ahead of your working out and answers, and highlight your final numerical answers (including units) by, for example, underlining or framing them.

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

The following lists of fundamental constants and formulas should be sufficient to answer all questions. However, in addition, standard booklets of fundamental constants or formulas, provided by your school, may be used.

Any calculators are allowed to be used.

Fundamental Constants

Electron charge	$e = 1.60 \times 10^{-19}$ C
Electron mass	$m_\mathrm{e} = 9.11 \times 10^{-31}$ kg
Gravitational constant	$G = 6.67 \times 10^{-11}$ m^3 kg^{-1} s^{-2}
Plank'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	$g = 9.8\ \mathrm{m\,s^{-2}}$
Mass of the 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	$1\ \text{Å} = 10^{-10}\ \mathrm{m}$
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	$T_{^\circ\mathrm{C}} = T_\mathrm{K} - 273.15$

Useful Formulas

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

$v = \frac{dx}{dt}$ $\quad a = \frac{dv}{dt}$ $\quad \omega = \frac{2\pi}{T}$ $\quad f = \frac{1}{T}$

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

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

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

$F = PA$ $\quad E = mc^2$ $\quad F_e = k\frac{qQ}{r^2}$ $\quad \rho = \frac{m}{V}$ $\quad A = \pi r^2$

$V = IR$ $\quad q = CV$ $\quad E_\mathrm{J} = Vq$ $\quad q = It$ $\quad q = Ne$

$\sum I_i = 0$ $\quad \sum V_i = 0$ $\quad \frac{1}{f} = \frac{1}{o} + \frac{1}{i}$ $\quad n_1 \sin\alpha_1 = n_2 \sin\alpha_2$ $\quad c = \frac{c_\mathrm{vacuum}}{n}$

/Continued overleaf/

SECTION A

Experimental Data Analysis of the Temperature Dependence of the Resistance of a Metal Wire

The Joule heat, E, generated by electric current, I, flowing through a metal wire was measured over a period of $t = 10$ s, while the room temperature, T, was varied. The potential difference between the two ends of the wire was $V = 4$ mV for all measurements. The Joule heat is:

$$E = \frac{V^2 t}{R} \qquad \text{(Eq. 1)}$$

The six measurements are:

T (°C)	–3.0	4.0	10.0	12.0	15.0	17.0
E (mJ)	55.4	53.5	52.0	51.5	50.8	50.3

(Table 1)

1)

Calculate the resistance, R, of the wire at each of the six temperatures. Round the values to three significant figures (3sf). [4]

2)

a) Plot the resistance, R, (from question 1) as a function of the room temperature, T. Error bars are not needed.

b) The results should show that, in the given temperature range, the resistance of the metal varies linearly with the temperature of its environment, that is:

$$R = mT + c \qquad \text{(Eq. 2)}$$

Draw a line that fits the data, then read the gradient, m, and y-intercept, c from the graph. [6]

3)

Given that:

$$m = R_0 \alpha \qquad \text{(Eq. 3)}$$

and

$$c = R_0(1 - \alpha T_0) \qquad \text{(Eq. 4)}$$

the linear relationship (described in question 2) can be rearranged to give:

$$R = R_0\big(1 + \alpha(T - T_0)\big) \qquad \text{(Eq. 5)}$$

where α is called the *temperature coefficient* of the resistance of the metal.

Using values for m and c found in question 2, and given that $T_0 = 20$ °C, solve Equations (3) and (4) for parameters R_0 and α. [4]

4)

Given the following metals and their respective temperature coefficients, the wire must be made of which metal? [2]

Aluminium ($\alpha_{\mathrm{Al}} = 0.00429\ ℃^{-1}$)

Copper ($\alpha_{\mathrm{Cu}} = 0.00386\ ℃^{-1}$)

Iron ($\alpha_{\mathrm{Fe}} = 0.00651\ ℃^{-1}$)

Platinum ($\alpha_{\mathrm{Pt}} = 0.00393\ ℃^{-1}$)

Silver ($\alpha_{\mathrm{Ag}} = 0.00380\ ℃^{-1}$)

Tungsten ($\alpha_{\mathrm{W}} = 0.00450\ ℃^{-1}$)

5)

If T is measured in Celsius degrees, °C, what can be the physical meaning of parameter R_0 in Equation (5)? [3]

6)

Assuming that the thermal behavior of the resistance of the wire in the range described in Table (1) can be extended to a temperature of $T = 25$ °C, use Equation (2) to predict the resistance of the wire at that temperature. Round the result to two significant figures(2sf). [3]

7)

A laboratory report describing the experiment results concluded that the resistance of the wire must become zero at temperature $\hat{T}$ where:

$$\hat{T} \equiv T_0 - \frac{1}{\alpha} = 20 - \frac{1}{0.0045} \approx -201.7\ ℃$$

Comment on the conclusion. [3]

SECTION B

1)

To what frequency does a music player have to be tuned to find the radio station which broadcasts at a wavelength of $\lambda = 200$ m ? [5]

2)

Water in Eikesdal Valley (Norway) dives into Eikesdalsvatn Lake from a height of $h = 630$ m. Assuming that 70 % of the potential energy of the water changes into its internal energy, how much is the temperature increase of the water during its fall? (The specific heat capacity of water is: $c = 4.2$ kJ kg^{-1} °C^{-1}) [5]

3)

What happens to the volume of an ideal gas in a piston when the gas pressure in the piston rises by 50 % while the gas is heated from $T_1 = 40$ °C to $T_2 = 60$ °C ? [5]

4)

The carbon-14 activity in a wooden archeological object was measured to be 78.5 % of the estimated original natural abundance. How old is the artifact?

(The half life of ${}^{14}_{6}C$ is $T = 5730$ yr. It can be assumed that the same amount of ${}^{14}_{6}C$ was initially present in the object as now in the fresh sample.) [5]

5)

A satellite (sat) at Point P along the line connecting the Sun (S) and the Earth (E) feels zero net gravitational force exerted by the Sun and the Earth:

$$F = F_S - F_E = \frac{GM_{sat}M_S}{D_S^2} - \frac{GM_{sat}M_E}{D_E^2} = 0$$

Here, $G = 6.67 \times 10^{-11}$ m^3 kg^{-1} s^{-2} is the gravitational constant, $M_{sat} = 3420$ kg, $M_S = 3 \times 10^{30}$ kg, and $M_E = 6 \times 10^{24}$ kg, are the masses of the satellite, Sun, and Earth, respectively, while D_S and D_E are distances of the satellite from the centres of the Sun and Earth, respectively.

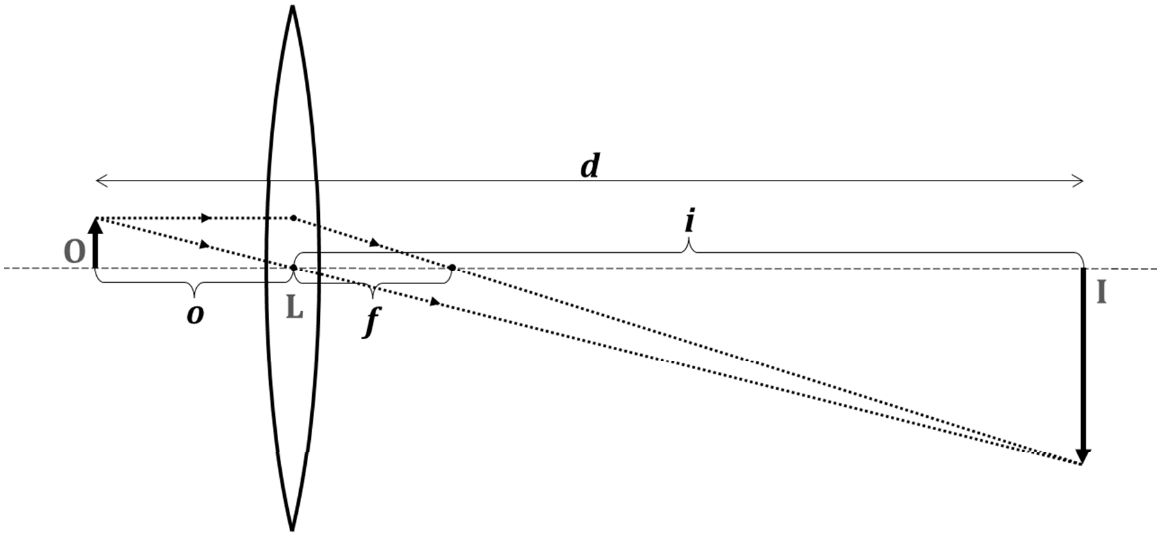
(Note that one astronomical unit is: $D = D_S + D_E = 1$ AU $= 1.5 \times 10^{11}$ m)

Finding the distance of point P from the centre of Earth ($D_E = ?$) calculate how many Earth-size objects could be fit along the line between the Earth and point P.

The Earth's diameter is: $d_E \approx 1.3 \times 10^7$ m [5]

6)

A thin lens creates a real image of an object at $d = 40$ cm away from the object. The size of the image is $M = 4$ times the size of the object. What is the focal length of the lens: $f = ?$



The thin lens equation is:

$$\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$$

where o and i are the distances of the object and the image from the lens, respectively. The ratio between the sizes of the image and object (magnification) equals the magnification of the lens: [5]

$$M = \frac{i}{o}$$

7)

The ampmeter in a circuit with a voltage, V, from a battery and three resistors, R_1, R_2, and R_3, (Figure 1) measures $I_1 = 1.5$ mA. What will the measured current be after swapping resistors R_1 and R_2 (Figure 2): $I_2 = ?$ [5]

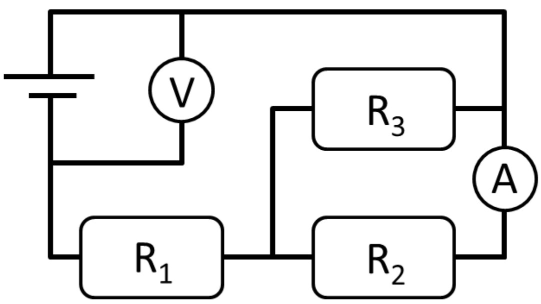


Figure 1

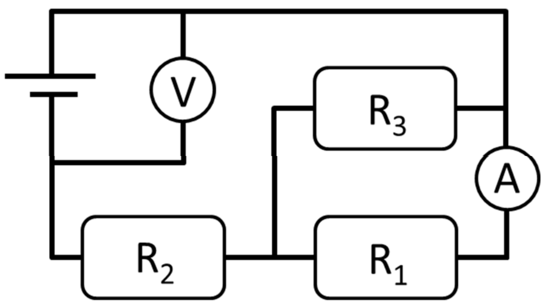


Figure 2