PRIFYSGOL ABERYSTWYTH UNIVERSITY

ENTRANCE SCHOLARSHIP EXAMINATION
JANUARY 2018

PHYSICS

Time allowed: **90 minutes**

The examination paper consists of two sections. Section A is data analysis for twenty four marks, while Section B has nine problem-solving questions, each for eight marks. The numbers in brackets at the end of the questions are the marks for correct and complete answers. Attempt to answer all questions in Section A. In Section B, the best seven, out of nine, marks will contribute to the total mark. The maximum total mark is 80 (= 24 + 7 × 8).

Use the notebook(s) provided to work out your solutions. Correct approaches, thoughts, ideas, and methods will be marked, even if the correct final answer is missing. No negative mark will be given for wrong arguments or incorrect answers.

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

Standard booklets of fundamental constants or formulae, provided by your school, can be used. The following lists, however, should be enough for all questions.

Any calculators are allowed to be used.

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	$G = 6.67 \times 10^{-11}\,\mathrm{m^3 kg^{-1} s^{-2}}$
Plank'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	$g = 9.81\ \mathrm{m\,s^{-2}}$
Mass of the alpha particle	$m_\alpha = 6.64\times10^{-27}\ \mathrm{kg}$
Boltzmann constant	$k = 1.38\times10^{-23}\ \mathrm{J\,K^{-1}}$
Astronomical unit	$1\ \mathrm{AU} = 1.5\times10^{11}\ \mathrm{m}$
Ångström	$1\ \mathrm{Å} = 10^{-10}\ \mathrm{m}$
Electronvolt	$1\ \mathrm{eV} = 1.6\times10^{-19}\ \mathrm{J}$
Avogadro number	$N_\mathrm{A} = 6.22\times10^{23}\ \mathrm{mol^{-1}}$
Temperature conversion	$T_{[^\circ\mathrm{C}]} = T_{[\mathrm{K}]} + 273.15$

Useful Formulas

$PV = NkT$ $\quad PV = nRT$ $\quad n = \dfrac{N}{N_\mathrm{A}}$ $\quad M = \dfrac{m}{n}$

$v(t) \equiv \dfrac{dx(t)}{dt}$ $\quad a(t) \equiv \dfrac{dv(t)}{dt}$ $\quad \omega = \dfrac{2\pi}{T}$

$s(t) = s_0 + u(t - t_0) + \dfrac{1}{2}a(t - t_0)^2$ $\quad v(t) = u + a(t - t_0)$ $\quad a_\mathrm{N} = \dfrac{v^2}{r}$

$E_\mathrm{kin} = \dfrac{1}{2}mv^2 = \dfrac{p^2}{2m}$ $\quad E_\mathrm{pot}(r) = -\dfrac{GMm}{r}$ $\quad E_\mathrm{pot} \approx mgh$ $\quad F_e(r) = k\,\dfrac{qQ}{r^2}$

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

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

$U = IR$ $\quad Q = CU$ $\quad E = UQ$ $\quad Q = It$ $\quad Q = Ne$

$\sum I_i = 0$ $\quad \sum U_i = 0$ $\quad \dfrac{1}{p} + \dfrac{1}{q} = \dfrac{1}{f}$ $\quad n_1 \sin\alpha_1 = n_2 \sin\alpha_2$ $\quad c = \dfrac{c_\mathrm{vacuum}}{n}$

SECTION A

Experimental Data Analysis

a)

When light with frequency f is shone onto a material, electrons can be emitted from the surface of the material with maximum kinetic energy

$$E_{\max} = hf - \Phi$$

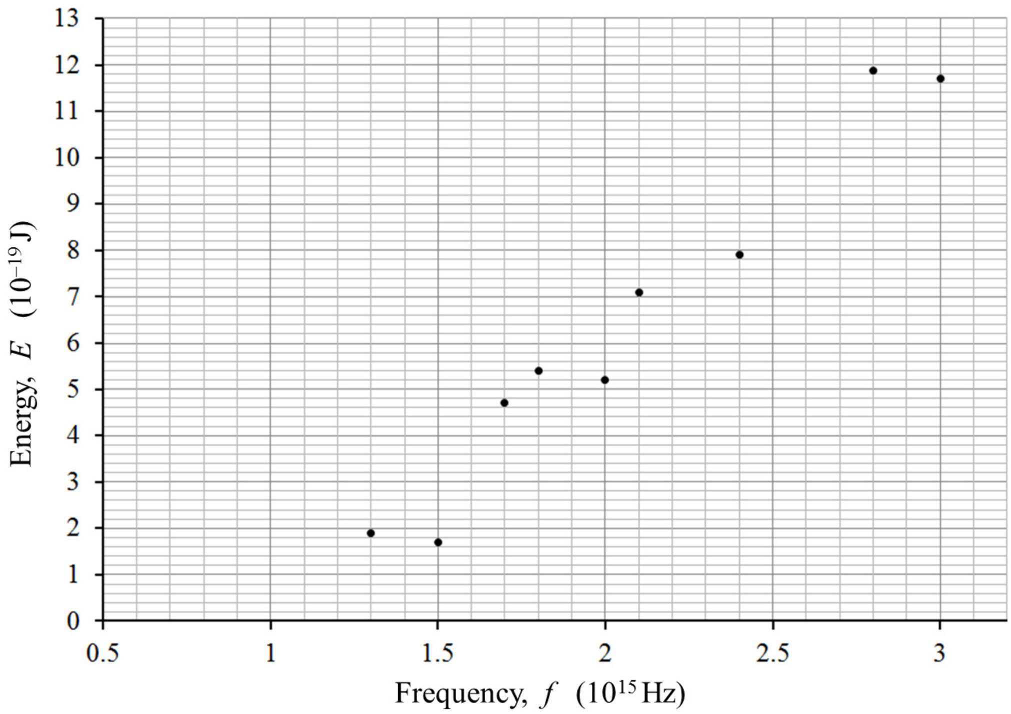
where h is Plank's constant.

i) Name the phenomenon. [2]

ii) What is the physical meaning of the work function, Φ? [4]

b)

The maximum kinetic energy of electrons emitted from a surface has been measured for nine different frequencies of the incident light.



i) At different measurements, the light beam reached different parts of the surface. Explain how the plotted results suggest that the surface is made up of at least two different materials. (Notice that, in the above equation, $E_{\max}$ is a linear function of f.) [5]

ii) Find a way to determine the work functions for the two materials, and, by that, decide which two of the following six elements could be present on the surface layer. [8]

Typical ranges of work functions for aluminium, barium, iron, nickel, palladium, and uranium, in 10^{-19} J, are $\Phi_{\text{Al}} = 6.5 - 6.8$, $\Phi_{\text{Ba}} = 4.0 - 4.3$, $\Phi_{\text{Fe}} = 7.5 - 7.7$, $\Phi_{\text{Ni}} = 8.1 - 8.9$, $\Phi_{\text{Pd}} = 8.4 - 9.0$, $\Phi_{\text{U}} = 5.8 - 6.2$, respectively.

c)
According to the laboratory diary recorded during the experiment, another measurement, with $E_{\max} = 1.31 \times 10^{-18}$ J for $f = 2.6 \times 10^{15}$ Hz, was observed, but left out from the final diagram, as it was considered an 'outlier' due to human error.
Assuming that the measurement was not a mistake after all, the presence of which material on the surface layer could have caused it? [5]

SECTION B

1 [8]
High up in the air, a balloon airship is rising with a constant vertical speed of $u = 0.7\text{ m s}^{-1}$ when a bag of mass $m = 15\text{ kg}$ is thrown out of it with a horizontal speed of $w = 1.4\text{ m s}^{-1}$. What will be the kinetic energy of the bag $t = 4\text{ s}$ later? (Air resistance can be ignored.)

2 [8]
In a mixture of isotopes A and B, the amount of isotope A initially is twice the amount of isotope B:

$$N_{\text{A}}(0) = 2N_{\text{B}}(0)$$

The half-life of isotope B is $T_{\text{B}} = 12.5\text{ day}$. Find the half-life of isotope A ($T_{\text{A}} = ?$) if, after $t = 10T_{\text{A}}$, the amount of isotope B becomes twice the amount of isotope A:

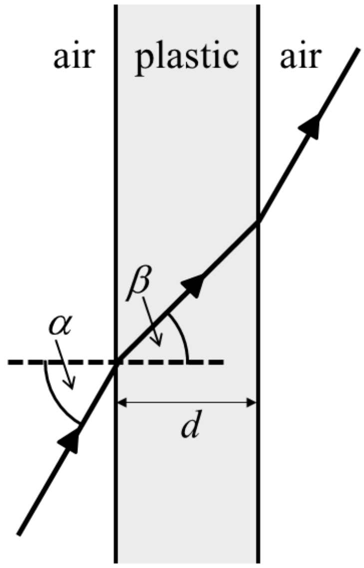
$$N_{\text{B}}(t) = 2N_{\text{A}}(t)$$

3 [8]
The current in an electric circuit made of copper wire is $I = 3\text{ A}$.
Assuming that there are $N = 6 \times 10^{22}$ free electrons in the wire, calculate the time it takes a free electron to move from one end of the wire to the other.

4 [8]
In a particular three-level laser, a population inversion is set up by pumping electrons (by infra-red radiation) from the ground state (level 0) to energy level 2. Calculate the frequency of the radiation emitted in the transition of electrons from level 2 to level 1. The energy levels are $E_0 = 0\text{ eV}$, $E_1 = 0.05\text{ eV}$, $E_2 = 0.13\text{eV}$.

5 [8]

A narrow beam of light passes through a layer of clear plastic as shown.
How much time does any particular part of the light beam spend in the plastic layer between entering and exiting it?
($\alpha = 60^{\circ}$, $\beta = 45^{\circ}$, $d = 0.1\,\text{m}$, refractive index of air is $n_{\text{air}} = 1$)



6 [8]

The temperature of an ideal (perfect) gas in a sealed container increased from $T_1 = 100\ ^{\circ}\text{C}$ to $T_2 = 400\ ^{\circ}\text{C}$, while the gas expanded from $V_1 = 1\,\text{m}^3$ to $V_2 = 4\,\text{m}^3$. What happened to the gas pressure during the expansion?

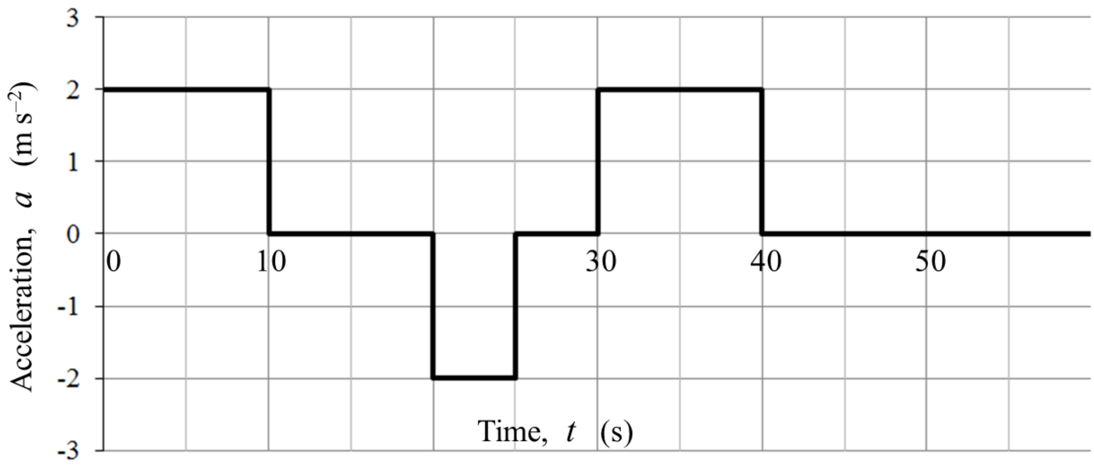
7 [8]

- Arcturus is the fourth brightest star in the night sky, it is 170 times brighter than the Sun, $L_{\text{A}} = 170 L_{\text{S}}$, where L is for luminosity.
- According to Wien's displacement law, the product of the surface temperature of a star and the wavelength at which the radiation intensity of the star is the highest is the same for every star. This maximum wavelength for Arcturus is 1.4 times larger than that for the Sun: $\lambda_{\text{max A}} = 1.4 \lambda_{\text{max S}}$
- The luminosity of a star is proportional to the square of the diameter of the star and also to the fourth power of the surface temperature (Stefan-Boltzmann law): $L \sim D^2 T^4$

Using the information provided above, work out how many times larger (in diameter) Arcturus is than the Sun.

8 [8]

A car is moving on a straight road. Its acceleration is shown below for $t \geq 0$.

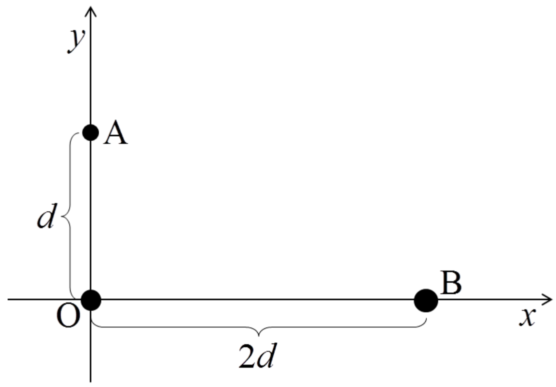


Sketch a speed vs. time graph in your answer booklet, and find the time when the car is a kilometre away from its initial ($t = 0$) position: $t_1 = ?$

9 [8]

Point charge O, with $q = 2\,\text{C}$, is placed into the origin of an xy plane. Three other point charges, A, B, and C, with $q_\text{A} = -1\,\text{C}$, $q_\text{B} = 4\,\text{C}$, and $q_\text{C} = 3\,\text{C}$, are fixed at three different positions in the xy plane in a way that the net force of the three fixed charges on q is zero.

The coordinates of A and B are $(x_\text{A}, y_\text{A}) = (0, d)$ and $(x_\text{B}, y_\text{B}) = (2d, 0)$, where $d = 971\,\text{mm}$.



What are the coordinates of point charge C:

$$(x_\text{C}, y_\text{C}) = ?$$

(The electrostatic force between charges q_1 and q_2 is $F = -k\dfrac{q_1 q_2}{r^2}$, where k is a positive constant, and r is the distance between the two charges. $F > 0$ and $F < 0$ indicate attraction and repulsion between the charges, respectively.)