THREE HOURS

A list of constants is enclosed.

UNIVERSITY OF MANCHESTER

General physics

23rd May 2019, 09:45 a.m. - 12:45

Answer as many questions as you can.
Marks will be awarded for your **THIRTEEN** best answers.

Each question is worth 10 marks.

Electronic calculators may be used, provided that they cannot store text.

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1. Sketch the distribution of speeds for molecules in a gas, and indicate the most probable speed. Calculate this for nitrogen at standard temperature and pressure.

2. A parallel-plate capacitor is made from two disks of area $1\,\mathrm{m}^2$, with a gap of 2 mm filled with a mica ($\epsilon_r = 7.2$) sheet. The capacitor is fully charged at a voltage of 100 V and disconnected from the power supply. What is the work done in removing the sheet?

3. Collimated white light is incident at an angle of 53° from the normal onto a thin film of refractive index $n = 1.33$. Calculate the minimum thickness of film that gives an intense yellow ($\lambda = 600\,\mathrm{nm}$) reflection, and state the polarisation of light that maximises the intensity of the reflection.

4. Give two signatures of nuclear saturation.

How does the Coulomb interaction in the semi-empirical mass formula depend on Z and A? Briefly explain your answer.

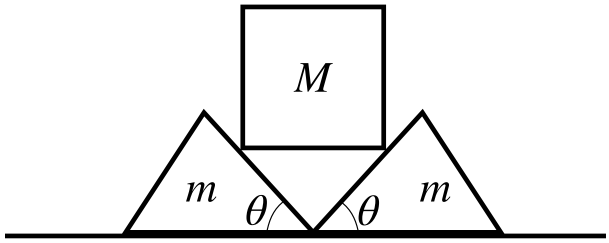
5. The amplitude of an underdamped oscillator as a function of time is given by

$$x(t) = x_0 e^{-\gamma t} \cos(\omega t)\,.$$

Given that $\gamma = (0.6 \pm 0.1)\ \mathrm{s}^{-1}$, $x_0 = 10.0$ m and $\omega = (20 \pm 1)\ \mathrm{s}^{-1}$, calculate the predicted amplitude and its uncertainty at a time $t = 2$ s.

6. An observation is made of an atomic transition at $\lambda_0 = 560\,\mathrm{nm}$ at positions across the face of the sun. A variation in transition wavelength of $\Delta\lambda = 8\times10^{-3}\,\mathrm{nm}$ is noted between observations at the two extrema along the solar equator. Calculate the period of solar rotation.

7. Two identical wedges, each of mass m, are placed next to each other on a flat floor. A cube of mass M is balanced on the wedges as shown in the figure. Assume no friction between the cube and the wedges, but a coefficient of static friction $\mu < 1$ between the wedges and the floor. Draw free-body diagrams for the cube and for one of the wedges. What is the heaviest cube that can be balanced without the wedges slipping?



8. A pion (mass 135 MeV/c^2) decays in flight into two photons, each with energy 100 MeV. How fast is the pion travelling? What is the opening angle between the photons?

9. State the law of mass action that relates the electron and hole concentrations, n and p respectively, in a semiconductor to the intrinsic carrier concentration n_i.

The relationship between the Fermi level (E_F) and intrinsic Fermi level (E_i) in a semiconductor is

$$E_F = E_i + \frac{k_B T}{2} \ln \left[\frac{n}{p} \right]. \tag{1}$$

In silicon at room temperature, where $k_B T$ is 0.025 eV, n_i is 10^{10} cm^{-3}. In the np junction of a silicon diode, the values of donor doping in the n-type and accepter doping in the p-type semiconductors are equal, and the potential difference (built-in potential) is 0.7 V Estimate the dopant concentration, N. State any assumptions you need to make.

10. A particle of mass m is in a 1-dimensional infinite square well with $V(x) = 0$ for $0 < x < a$. At $t = 0$ the wave function is

$$\psi(x) = \frac{2}{\sqrt{a}} \sin\left(\frac{3\pi x}{a}\right) \cos\left(\frac{\pi x}{a}\right).$$

If the energy is measured, what possible values may be obtained, with what probabilities? Write down the wave function at a subsequent time $t = \dfrac{ma^2}{2\pi\hbar}$.

11. An exoplanet is entirely eclipsed by its host star once per orbit, at which point the observed brightness of the system drops by 1 part in 10^6 compared to the regular out-of-eclipse level. From a spectral analysis, the observer can identify two approximate blackbody spectra of the star and the exoplanet, peaking at wavelengths 500 and 2900 nm respectively. Assuming that all the observed brightness is solely due to the blackbody emission from each source, determine the ratio of the radius of the planet to that of the star.

12. A tunnel is cut through the centre of the Earth, through which a 1 kg mass is dropped. Assume the Earth is a sphere of uniform density, and a linear drag of $F_d = -bv$ is experienced by the mass, where v is particle velocity and $b = 10^{-4}\,\mathrm{Ns/m}$. Calculate the natural frequency ω_0 and Q-factor of the system.

13. a) Fourier's law of heat transfer in 1D is given by

$$\frac{\mathrm{d}Q}{\mathrm{d}t} = \frac{\Delta T}{R},$$

where $\mathrm{d}Q/\mathrm{d}t$ is the heat transfer, ΔT is the temperature difference across the sample, and R is the thermal resistance.

Give an expression for the thermal resistance of a rectangular slab in terms of the thickness d, area A and thermal conductivity κ.

b) An Intel CPU has a maximum temperature rating of 72 °C. Its thermal power rating is 95 W. It has a package size of 37.5 mm by 37.5 mm. The CPU is glued to a heatsink that has a thermal resistance of 0.4 °C/W. The glue layer has a thermal resistance of 0.1 °C/W if properly applied.

i) Determine if the CPU will exceed its maximum temperature in this case.

ii) In a particular sample, the thermal glue has been poorly applied over 30% of the area and has decreased its thermal conductivity by a factor five in these regions. Will the maximum temperature be exceeded?

14. We place a charge q at height h above the middle of a large, grounded, conducting plate. Find the charge density on the plate.

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15. Two rockets, A and B, depart simultaneously from the Earth in opposite directions at speeds of $0.8c$. What is the relative velocity of the two rockets? After a year as measured in its own rest frame, rocket B emits a light signal. When an observer in rocket A detects the signal, how much older is she than at departure?

END OF EXAMINATION PAPER