THREE HOURS

A list of constants is enclosed.

UNIVERSITY OF MANCHESTER

General Physics

19th May 2006, 9.45 a.m. - 12.45 p.m.

THREE HOUR CANDIDATES

(Physics, Physics with Astrophysics, Physics with Theoretical Physics, Physics with Technological Physics)

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

TWO HOUR CANDIDATES

(Maths/Physics, Physics with Business and Management, Physics with Computing and IT, Physics with Finance, Physics with Philosophy)

Answer as many questions as you can from questions 1-10 inclusive. Marks will be awarded for your NINE best answers.

Each question is worth 10 marks.

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

The numbers are given as a guide to the relative weights of the different parts of each question.

1. An object of mass m attached to a spring of spring constant k undergoes simple harmonic motion of amplitude A. Write down expressions for the total energy, E, and the maximum speed, v_{max}, of the object in terms of the given constants.

At what positions is the speed of the object equal to half its maximum value, if the amplitude is equal to 4.00 cm?

2. Sketch energy level diagrams for a particle in the following potentials: (a) an infinite square well; (b) an harmonic oscillator; and (c) Coulomb ($V(r) = -$ const$/r$). For each case state the energy-dependence on the principal quantum number, n.

3. Sketch the variation of the nuclear binding energy per nucleon as a function of nuclear mass. With reference to this diagram, explain why energy is released when a ^{235}U nucleus fissions.

4. Titan has a dense atmosphere which is largely composed of nitrogen molecules. Titan's surface temperature is 94 K, its mass is 1.345×10^{23} kg and its radius is 2575 km. At the surface the atmospheric pressure is 1.5 bar. Estimate the height above the surface at which the atmospheric pressure is reduced to 1 bar.

5. An ion is placed inside a closed metal box. A hole is drilled in a wall of the box. In which direction is the force on the ion? Give reasons for your answer.

6. An electron with energy $E = 3$ eV moves along a cyclotron orbit in a magnetic field of 0.001 T. Calculate the radius of the orbit.

7. A heat pump whose efficiency is 85% of the theoretical maximum extracts heat from the atmosphere at 5° C to heat a building to a temperature of 18° C. Estimate the cost of providing 1 kWhr of heat to the building if 1 kWhr of electricity costs 7.5p.

P.T.O.

8. A stabilized dye laser operating at 589.300 nm has a Gaussian linewidth of ± 3 GHz. This laser beam is passed through sodium atoms in an atomic beam whose doublet D-lines can be excited at wavelengths of 589.600 nm and 589.000 nm. Determine whether the laser beam is likely to excite the sodium atoms (ignore Doppler effects and pressure broadening when calculating your answer).

9. A Michelson interferometer is set up using a vertically polarized, highly coherent helium neon laser as the light source to give fringes which can be viewed on a card. A variable liquid crystal (LC) retardation plate is placed in one of the arms of the interferometer, such that the optic axis of the retardation plate is at 45° to the vertical. The LC retarder can vary the retardation through a full wave without changing the thickness of the plate, by applying a voltage to the liquid crystal cell.

Describe what the effect on the fringe visibility will be as the LC retarder continuously changes the retardation from 0λ to 1λ by application of a control voltage.

10. A bowling ball is rolling without slipping up an inclined plane. As it passes a point O it has a speed of 2.00 ms^{-1} up the plane. It reaches a vertical height h above O before momentarily stopping and rolling back down. Determine the value of h.

If a hollow ball, composed only of a thin shell, underwent similar motion also moving at a speed of 2.00 ms^{-1} at O, would the height it reached be less than, equal to, or greater than that of the solid bowling ball? Give reasons for your answer.

[The moment of inertia of a solid sphere of mass m and radius r is $I = 2mr^2/5$.]

11. By dimensional analysis or otherwise, deduce the form of the resistive force experienced by a spherical body falling through a medium such as air in which viscosity can be ignored. Hence make a rough estimate of the terminal velocity of a raindrop weighing 10^{-3} g. (The density of air is 1.2 kg m^{-3}.)

12. In graphene which is a two-dimensional crystal, the electrons behave as if they were an ideal gas of fermions with the dispersion relation $\epsilon = pv_0$, where their velocity v_0 is 10^6 ms^{-1}. If their density per unit area is 10^{16} m^{-2}, what is their Fermi energy in eV?

P.T.O.

13. The six lowest-lying excited levels of the helium atom have configurations which have one electron in the $1s$ orbital and the second electron in the $n = 2$ level. Give the quantum numbers (orbital angular momentum L, spin angular momentum S, total angular momentum J) for each of the levels.

14. The sun is a star of absolute magnitude +4.8, but on earth its apparent magnitude is −26.8. What will the apparent magnitude be from Jupiter? (Note: The orbital radius of Jupiter is 5.20 AU, and 1 parsec is 2.06×10^5 AU.)

15. A particle of mass 2.00 MeV/c^2 and kinetic energy 3.00 MeV collides with a stationary particle of mass 4.00 MeV/c^2. After the collision, the two particles stick together. What is the initial momentum of the incoming particle? What is the final velocity of the two-particle system?

END OF EXAMINATION PAPER

PHYSICAL CONSTANTS AND CONVERSION FACTORS

SYMBOL	DESCRIPTION	NUMERICAL VALUE
c	Velocity of light in vacuum	299 792 458 m s^{-1}, exactly
μ_0	Permeability of vacuum	$4\pi \times 10^{-7}$ N A^{-2}, exactly
ϵ_0	Permittivity of vacuum where $c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$	8.854×10^{-12} C^2 N^{-1} m^{-2}
h	Planck constant	6.626×10^{-34} J s
$\hbar$	$h/2\pi$	1.055×10^{-34} J s
G	Gravitational constant	6.674×10^{-11} m^3 kg^{-1} s^{-2}
e	Elementary charge	1.602×10^{-19} C
eV	Electronvolt	1.602×10^{-19} J
α	Fine-structure constant, $\frac{e^2}{4\pi\epsilon_0 \hbar c}$	$\frac{1}{137.0}$
m_e	Electron mass	9.109×10^{-31} kg
$m_e c^2$	Electron rest-mass energy	0.511 MeV
μ_B	Bohr magneton, $\frac{e\hbar}{2m_e}$	9.274×10^{-24} J T^{-1}
R_∞	Rydberg energy $\frac{\alpha^2 m_e c^2}{2}$	13.61 eV
a_0	Bohr radius $\frac{1}{\alpha}\frac{\hbar}{m_e c}$	0.5292×10^{-10} m
Å	Angstrom	10^{-10} m
m_p	Proton mass	1.673×10^{-27} kg
$m_p c^2$	Proton rest-mass energy	938.272 MeV
$m_n c^2$	Neutron rest-mass energy	939.566 MeV
μ_N	Nuclear magneton, $\frac{e\hbar}{2m_p}$	5.051×10^{-27} J T^{-1}
fm	Femtometre or fermi	10^{-15} m
b	Barn	10^{-28} m^2
u	Atomic mass unit, $\frac{1}{12}\, m(^{12}\text{C atom})$	1.661×10^{-27} kg
N_A	Avogadro constant, atoms in gram mol	6.022×10^{23} mol^{-1}
T_t	Triple-point temperature	273.16 K
k	Boltzmann constant	1.381×10^{-23} J K^{-1}
R	Molar gas constant, $N_A k$	8.315 J mol^{-1} K^{-1}
σ	Stefan-Boltzmann constant, $\frac{\pi^2}{60}\frac{k^4}{\hbar^3 c^2}$	5.670×10^{-8} W m^{-2} K^{-4}
M_E	Mass of Earth	5.97×10^{24} kg
R_E	Mean radius of Earth	6.4×10^6 m
g	Standard acceleration of gravity	9.806 65 m s^{-2}, exactly
atm	Standard atmosphere	101 325 Pa, exactly
$M_\odot$	Solar mass	1.989×10^{30} kg
$R_\odot$	Solar radius	6.961×10^8 m
$L_\odot$	Solar luminosity	3.846×10^{26} W
$T_\odot$	Solar effective temperature	5800 K
AU	Astronomical unit, mean Earth-Sun distance	1.496×10^{11} m
pc	Parsec	3.086×10^{16} m
	Year	3.156×10^7 s