EXAMINATION PAPER CONTAINS STUDENT'S A[illegible]S

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The Handbook of Mathematics, Physics and Astronomy Data is provided

KEELE UNIVERSITY

EXAMINATIONS, 2010/11

Level I

Friday 14th January 2011, 16:00 - 18:00

PHYSICS/ASTROPHYSICS

PHY-10024

Nature of Matter

Candidates should attempt ALL of PARTS A and B, and TWO questions from PART C. PARTS A and B should be answered on the exam paper; PART C should be answered in the examination booklet which should be attached to the exam paper at the end of the exam with a treasury tag.
PART A yields 16% of the marks, PART B yields 24%, PART C yields 60%.

Please do not write in the box below

A		C1		Total
B		C2		
		C3		
		C4		

NOT TO BE REMOVED FROM THE EXAMINATION HALL

PART A **Tick the one box by the answer you judge correct (marks are not deducted for incorrect answers)**

A1 The molecules in 1 kg-mole of an ideal diatomic gas rotate but do not vibrate. The internal energy of the gas, according to the classical Equipartition Theorem, is

☐ $\frac{1}{2}RT$ ☐ $\frac{3}{2}RT$ ☐ $\frac{5}{2}RT$ ☐ $\frac{7}{2}RT$ [1]

A2 An isolated system is taken very slowly from an initial state to a final state. During this process, an amount of heat Q enters the system, and work W is done by the system. What other property of the system changes during this process?

☐ chemical composition ☐ mass
☐ temperature ☐ number of moles [1]

A3 If a system undergoes an isothermal change then

☐ its temperature rises at a constant rate
☐ there is no exchange of energy with the surroundings
☐ no work is done on or by the system
☐ the temperature of the system stays constant [1]

A4 The Kinetic Theory of gases works best for

☐ diatomic gases
☐ gases just above their liquefaction point
☐ gases at low densities
☐ gases at very high densities [1]

A5 On a phase diagram, the *triple point* describes the point at which

☐ three different gases can co-exist independently in a gas mixture
☐ all three phases of a substance (gas, liquid, solid) can co-exist
☐ the point at which tri-atomic gases (such as CO_2) are found
☐ a solid can exist in three different crystalline forms [1]

A6 The molar specific heat at constant pressure, C_p, of a mo as is

- ☐ always greater than
- ☐ the same as
- ☐ sometimes less than, sometimes greater than
- ☐ always less than [1]

the specific heat at constant volume C_v.

A7 Hydrogen *atoms* in the interstellar gas display

- ☐ translational motion only
- ☐ translational and rotational motion
- ☐ translational and vibrational motion
- ☐ translational, rotational and vibrational motion [1]

A8 The mean free path of a molecule in a gas is

- ☐ the total distance travelled by a molecule in a gas
- ☐ the average distance travelled by a molecule between collisions
- ☐ the path a molecule travels in a gas
- ☐ the mean path travelled by molecules in a gas [1]

A9 The binding energy of a valence (outer) electron in an atom is typically

☐ a few eV ☐ a few keV ☐ a few MeV ☐ a few J [1]

A10 The 'dimensions' of an atom are typically

☐ 10^{-15} m ☐ 10^{-10} m ☐ 10^{-18} m ☐ 10^{-6} m [1]

A11 The de Broglie wavelength of an electron is, in the usual notation,

☐ hf ☐ hp ☐ h/p ☐ p/h [1]

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A12 Which of the following indicate the photon (i.e. 'particle') of electromagnetic radiation?

- ☐ interference
- ☐ the Compton effect
- ☐ constancy of speed in any inertial reference frame
- ☐ diffraction [1]

A13 Classical physics fails to explain the photoelectric effect because the measured kinetic energy of the emitted electrons

- ☐ depends on the intensity of the incident light
- ☐ depends on the frequency of the incident light
- ☐ does not depend on the properties of the incident light
- ☐ is the same for all surfaces [1]

A14 ^{18}O and ^{16}O are both isotopes of oxygen because they

- ☐ contain the same number of neutrons in the nucleus
- ☐ contain the same number of particles in the nucleus
- ☐ contain the same number of protons in the nucleus
- ☐ contain the same number of electrons in the nucleus [1]

A15 The binding energy of an atomic nucleus is

- ☐ the energy needed to disperse its constituent nucleons
- ☐ the total energy of its constituent nucleons (including rest mass)
- ☐ the total energy of the electrons in the nucleus (including rest mass)
- ☐ the sum of the kinetic energies of its constituent nucleons [1]

A16 In the nuclear reaction $^{12}_{6}C + {}^{12}_{6}C \rightarrow {}^{20}_{10}Ne + X$, identify X:

☐ $^{6}_{3}Li$ ☐ $^{14}_{6}C$ ☐ $^{4}_{2}He$ ☐ $^{3}_{1}H$ [1]

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PART B Answer all EIGHT questions

B1 A gas at pressure P is contained in a cylindrical vessel. The gas does work on a friction-free piston by raising it by a small distance dx. Show that the work done by the gas is $dW = P\,dV$, where dV is the change in gas volume. [3]

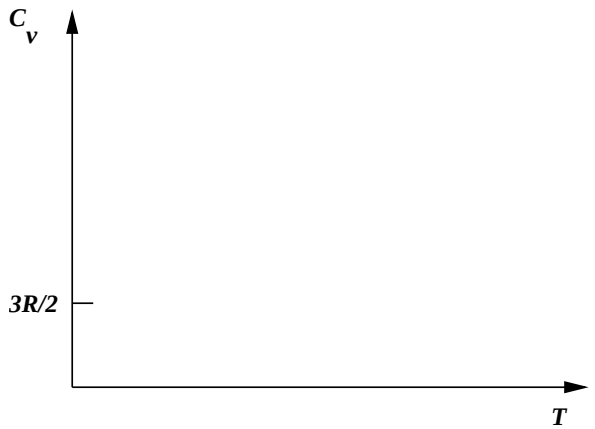
B2 For an ideal gas at temperature T, each degree of freedom can be ascribed a mean energy $\frac{1}{2}k_{\mathrm{B}}T$. Use this to determine the internal energy U for 1 kg of an ideal monatomic gas having atomic weight A. [3]

B3 The van der Waals equation of state is

$$\left(P + \frac{a}{V^2}\right)(V - b) = RT \ ,$$

in the usual notation. Sketch the phase diagram (i.e. P against V) for a gas obeying the van der Waals equation of state, for two temperatures; one well above the critical temperature T_c and one well below T_c. [3]

B4 Sketch the temperature-dependence of the specific heat at constant volume C_v for (i) a diatomic gas (like N_2) and (ii) a monatomic gas (like He). [3]



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B5 What is the de Broglie wavelength associated with a [illegible] which has kinetic energy 10 keV?

B6 A radio transmitter operating at frequency 3 000 MHz has power 2 W. How many photons does it emit per second? [3]

B7 In a photoelectric effect experiment, a metal with work function 3.1 eV is irradiated with radiation. If the maximum kinetic energy of the ejected electrons is 1.87 eV what is the wavelength of the incident radiation? [3]

B8 Sketch the dependence of the binding energy per nucl
atomic nuclei as a function of atomic mass.

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PART C Answer TWO out of FOUR questions

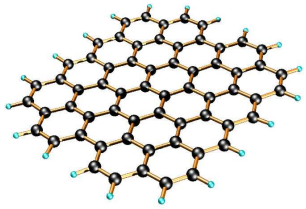
C1 (a) In the context of kinetic theory, what is a *degree of freedom*? [2]

(b) What is the theorem of Equipartition of Energy? [2]

(c) Show that the Equipartition Theorem leads to a value of $C_V = 3R$ for the molar specific heat of a solid, where R is the universal gas constant. [10]

(d) Sketch the actual temperature-dependence of the molar specific heat at constant volume for a solid. Identify on your sketch the temperature range over which the specific heat is consistent with classical physics, and the temperature range over which classical physics is inadequate. [2 × 2]

(e) The figure shows the 2-dimensional structure of graphene. Estimate C_V for this material. [12]



C2 (a) Describe briefly what is meant by (i) an ionic bond, (ii) a covalent bond, (iii) a van der Waals bond, (iv) co-ordination number. [4 × 2]

(b) Rank the bonds in terms of strength, strongest first, weakest last. [6]

(c) Which of these bonding processes is important in liquid oxygen, which consists of oxygen molecules O_2 ? [6]

(d) The latent heat of vapourization of liquid oxygen is 213 kJ kg^{-1}. Estimate the strength of the bond in liquid oxygen, and hence deduce the nature of the bond in terms of the above three alternatives. [10]

C3 (a) Describe the photoelectric effect, and explain why it c
understood on the basis of classical physics.

(b) Outline Einstein's theory of the photoelectric effect. [1

(c) In a photoelectric effect experiment, monochromatic radiation of wavelength $\lambda = 260$ nm is incident on a metal surface. The maximum kinetic energy of the ejected electrons is found to be 1.55 eV. What is the work function for the metal, and what is the maximum electron kinetic energy if radiation with $\lambda = 395$ nm is used? [10]

C4 (a) Radiation is used to observe an electron. Show that the uncertainty in the position of the electron, Δx, and the uncertainty in its momentum, Δp, are related by

$$\Delta x \ \Delta p \simeq h \, ,$$

where h is Planck's constant. [10]

(b) What is an alternative form of the Uncertainty Principle? [2]

(c) An alpha particle ($^4_2$He) is confined within an atomic nucleus, of dimensions $\sim 7 \times 10^{-15}$ m. Assuming its speed is $\ll c$, what is the uncertainty in its speed? [8]

(d) A photon of wavelength 500 nm forms a virtual $e^- \, e^+$ pair. Estimate the time that elapses before the photon is reconstituted. [10]