EXAMINATION PAPER CONTAINS STUDENT'S ANSWERS

Please write your 8-digit student number here: ☐☐☐☐☐☐☐☐

The Handbook of Mathematics, Physics and Astronomy Data is provided

KEELE UNIVERSITY

EXAMINATIONS, 2009/10

Level I

Monday 18$^{\text{th}}$ January 2010, 09.30-11.30

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%. You are advised to divide your time in roughly these proportions.
Figures in brackets [ ] denote the marks allocated to the various parts of each question.

Please do not write in the box below

A		C1		Total
B		C2		
		C3		
		C4		

NOT TO BE REMOVED FROM THE EXAMINATION HALL

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PART A TICK THE BOX BY THE ANSWER YOU JUDGE TO BE CORR
(MARKS ARE NOT DEDUCTED FOR INCORRECT ANSWERS)

A1 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]

A2 The equipartition theorem gives a satisfactory explanation of

- ☐ the temperature dependence of the specific heats of gases
- ☐ the temperature dependence of the specific heats of solids
- ☐ the temperature dependence of the latent heats of fusion of solids
- ☐ none of the above [1]

A3 The molar specific heat at constant volume, C_V, of a monatomic gas is

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

the specific heat at constant pressure C_P.

A4 Heat is added to a gas, which is kept at constant volume. The gas

- ☐ does work on its surroundings
- ☐ does no work on its surroundings
- ☐ has work done on it by the surroundings
- ☐ stays at the same temperature as its surroundings [1]

A5 A system is taken very slowly from an initial state to a final state. During this process, the heat Q entering the system, and the work W done by the system, are measured. What other property of the system changes during this process?

- ☐ mass
- ☐ number of moles
- ☐ internal enegy
- ☐ ratio of specific heats [1]

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A6 Molecules in a hot diatomic gas display

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

A7 Which of the following is *not* a state variable of an ideal gas?

- ☐ pressure
- ☐ boiling point
- ☐ internal energy
- ☐ temperature [1]

A8 In an adiabatic change in a gas,

- ☐ the pressure of the gas is held constant
- ☐ the temperature of the gas is held constant
- ☐ the gas cools at a constant rate
- ☐ the gas is thermally isolated from its surroundings [1]

A9 An atomic nucleus has $Z = 40, N = 40$ (where Z and N are respectively the atomic number and neutron number for the nucleus). Identify its isotope.

- ☐ $Z = 41, N = 41$
- ☐ $Z = 41, N = 40$
- ☐ $Z = 40, N = 42$
- ☐ $Z = 42, N = 40$ [1]

A10 The binding energy of an outer electron in an atom is typically

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

A11 The 'dimensions' of an atomic nucleus are typically

- ☐ 10^{-15} m
- ☐ 10^{-9} m
- ☐ 10^{-18} m
- ☐ 10^{-6} m [1]

A12 The uncertainty principle limits simultaneous knowledge of

- ☐ energy and velocity
- ☐ energy and momentum
- ☐ momentum and position
- ☐ time and position [1]

A13 During a nuclear reaction, which of the following *need not* be conserved?

- ☐ charge
- ☐ momentum
- ☐ neutron number
- ☐ lepton number [1]

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A14 Which one of the following indicates the wave nature of electromagne[illegible]n?

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

A15 Quantum mechanics predicts that, at absolute zero of temperature,

☐ all motion ceases
☐ there is a residual motion due to the uncertainty principle
☐ matter ceases to exist
☐ everything collapses to zero volume [1]

A16 Which is the weakest of the four fundamental interactions of Nature?

☐ strong nuclear
☐ electromagnetic
☐ gravitation
☐ weak nuclear [1]

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B1 For an ideal gas at temperature T, each degree of freedom can be ascribed an average energy $\frac{1}{2}k_{\mathrm{B}}T$. Use this to determine the molar specific heat at constant volume, C_{V}, for an ideal monatomic gas. [3]

B2 The density of solid arsenic is $5730\,\mathrm{kg\,m^{-3}}$. Estimate the distance between arsenic atoms in a piece of solid arsenic. [3]

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B3 It is desired to see a virus, of dimensions 6 nm, using an electron mic
What is the minimum voltage is needed to accelerate the electrons?

B4 The potential energy E of one ion in the field of another in a solid is described by the formula

$$E = -\frac{A}{r^6} + \frac{B}{r^{12}} ,$$

where A and B are constants and r is the distance between the ions. Sketch the variation of E with r; include on your diagram the variation of each of the terms contributing to the total potential energy; indicate on your diagram the equilibrium separation of the two ions. [3]

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B5 Photons of wavelength 590 nm are emitted by a 50 W sodium lamp. Ho

photons are emitted per second?

B6 A burglar alarm consists of a photoelectric cell for which the work function is 2.5 eV. Knowing this, a burglar covers her torch with a filter that transmits only light having wavelength longer than 520 nm. Determine whether the light from the torch will activate the alarm. [3]

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B7 Sketch the temperature-dependence of the specific heat at constant vo[...]
for a diatomic gas. Label the essential features of the plot.

B8 The mass of a proton is 1.007825 atomic mass units (amu), the mass of a neutron is 1.008665 amu, while the mass of a deuteron ($^2_1$H) is 2.014102 amu. If 1 amu $= 1.6604 \times 10^{-27}$ kg, calculate the binding energy of a deuteron in MeV. [3]

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PART C Answer TWO out of FOUR questions

C1 (a) What is the theorem of Equipartition of Energy?

(b) Show that, for a simple 3-dimensional crystalline solid, the Equipartition Theorem gives the result $C_V = 3R$ for the molar specific heat. [6]

(c) The specific heat at constant volume of an unknown (elemental) solid is measured at high temperature to be $260.0\,\mathrm{J\,kg^{-1}\,K^{-1}}$. Estimate its atomic weight and identify the element. [5]

(d) Sketch the *actual* temperature-dependence of the specific heat at constant volume C_V for a solid. Indicate on your diagram how the classical value differs from the actual behaviour. [5]

(e) Determine the molar specific heat at constant volume for a *2-dimensional* solid. [10]

C2 (a) What is meant by the *mean free path* for a molecule in a gas? [2]

(b) Show that the mean free path λ is given by

$$\lambda = \frac{1}{n\pi d^2} ,$$

where n is the number of molecules per unit volume and d is the molecular diameter. You may assume that all the molecules are identical. [10]

(c) Estimate the mean free path for the following:

i. one of the 10^6 stars in the core of a globular cluster, each of which has diameter 6×10^8 m, and which are confined to a volume $10^{50}\mathrm{m}^3$; [4]

ii. a hydrogen atom, of diameter 10^{-10} m, in interstellar space, where there are 10^5 H atoms m^{-3} [4]

(d) Which of these estimates is the more reliable? Explain your answer. [10]

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C3 (a) Give a qualitative account of the Compton effect, and indicate not be understood on the basis of classical physics.

(b) In a Compton scattering experiment, X-rays of incident wavelength λ scattered by 'stationary' electrons; X-rays scattered at angle θ to the incident direction have wavelength λ', where

$$\lambda' - \lambda = \frac{h}{mc}\,(1 - \cos\theta) \quad .$$

The incident X-rays have wavelength $\lambda = 0.0150\,\text{nm}$. What is the wavelength of X-rays scattered at 45°? [5]

(c) What is the corresponding kinetic energy of the recoil electrons? [10]

(d) What is the maximum possible wavelength of scattered X-rays? [5]

(e) If the electrons were replaced by protons in the Compton scattering experiment, how would the wavelength of the scattered X-rays differ, other things being equal? [5]

C4 High energy electrons, with a specific energy, are used to bombard a solid (elemental) surface; as a consequence, X-rays are emitted.

(a) Sketch the dependence of the intensity of X-rays on X-ray wavelength. Give a physical explanation for the essential features of the plot. [8]

(b) Describe Moseley's interpretation of the "characteristic" X-rays emitted. [8]

(c) What property of the atomic nucleus does this experiment reveal? [4]

(d) A certain metal is bombarded with electrons and X-rays with characteristic energy 8028 eV are emitted. Identify the metal. [10]

[N.B. You may assume that the Bohr formula for the wavelength λ of the photon emitted when an electron undergoes a transition from n_2 to n_1 is

$$\frac{1}{\lambda} = R_\infty Z^2 \left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

where R_∞ is the Rydberg constant and Z is the atomic number.]