EXAMINATION PAPER CONTAINS STUDENT'S ANSW

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The Handbook of Mathematics, Physics and Astronomy Data is provided

KEELE UNIVERSITY

EXAMINATIONS, 2011/12

Level I

Wednesday 11$^{\text{th}}$ January 2012, 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 box by the answer you judge to be cor
(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 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]

A4 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 energy
- ☐ ratio of specific heats [1]

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A5 Molecules in a hot diatomic gas display

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

A6 Which of the following is *not* a state variable of an ideal gas?

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

A7 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]

A8 The uncertainty principle limits simultaneous knowledge of

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

A9 During a nuclear reaction, which of the following *need not* be conserved?

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

A10 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]

A11 The size of an atomic nucleus is typically

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

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A12 Which one of the following indicates the wave nature of electr[omag]netic radiation?

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

A13 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]

A14 Atomic number Z, atomic mass number A and neutron number N are related by

- ☐ $A = Z - N$
- ☐ $A = Z + N$
- ☐ $A = Z + N + 2$
- ☐ $Z = N - A$ [1]

A15 Which is the strongest of the four fundamental interactions of Nature for two protons separated by 10^{-15} m?

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

A16 In the nuclear reaction ${}^{16}_{8}\mathrm{O} + {}^{16}_{8}\mathrm{O} \rightarrow {}^{31}_{15}\mathrm{P} + \mathrm{X}$, identify X:

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

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PART B Answer all EIGHT questions

B1 How many ^{40}Ca atoms are there in a vessel containing 100 g of ^{40}Ca? [3]

B2 Write down the first law of thermodynamics, explaining the meaning of each term (including their sign). [3]

B3 Briefly describe two different molecular bonds in solids and compare their strength. [3]

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B4 A burglar alarm consists of a photoelectric cell for which the wo[rk] function is 2.0 eV. Knowing this, a burglar covers her torch with a filter that transmits only light having wavelength longer than 600 nm. Determine whether the light from the torch will activate the alarm. [3]

B5 The Rydberg formula gives the wavelength λ of lines emitted by a hydrogen-like atom with nuclear charge Z:

$$\frac{1}{\lambda} = R\, Z^2 \left(\frac{1}{n^2} - \frac{1}{m^2} \right)$$

where the Rydberg constant $R = 1.09737 \times 10^7\,\mathrm{m}^{-1}$ and n and m are integers. Where in the spectrum would you find emission from a C^{5+} ion in which an electron makes a transition from $m = 3$ to $n = 2$? [3]

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B6 What is the kinetic energy of electrons suitable for studying atom using electron diffraction? [3]

B7 Describe the Compton effect and explain why classical physics cannot explain it. [3]

B8 Sketch the dependence of the binding energy per nucleon for atomic nuclei as a function of atomic mass, including key features of the plot. [3]

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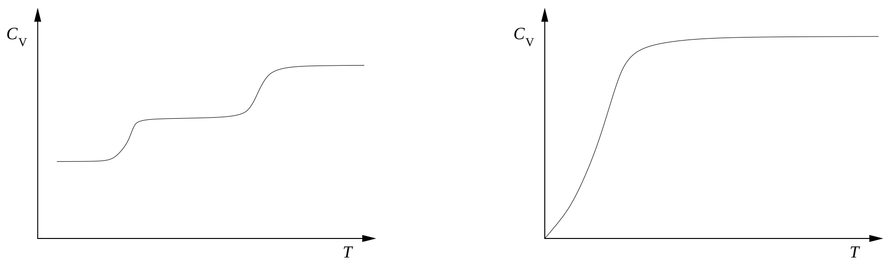
PART C Answer TWO out of FOUR questions

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) The figure below shows the temperature-dependence of the specific heat at constant volume for a diatomic gas (left) and a solid (right).



Explain, without using mathematics, the essential features of these diagrams. [10]

(d) Assuming that $C_p - C_v = R$, in the usual notation, use the Equipartition Theorem to show that the ratio of specific heats $C_p/C_v = \gamma$ has the value 9/7 for a gas consisting of diatomic molecules that both rotate and vibrate. [10]

(e) Would you expect this result to be valid for low, intermediate or high temperatures? Explain your answer. [6]

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C2 (a) What is meant by

i. an adiabatic process [2]

ii. an isothermal process? [2]

(b) Neon gas, at initial temperature, $T = 20°$ C, and pressure, $P = 1$ atm, is compressed isothermally to one fifth (1/5) its initial volume. Determine the pressure and the temperature after compression. [10]

(c) If the compression in part (b) had been performed adiabatically rather than isothermally, what would the pressure and temperature following compression be, assuming that the gas had the same initial conditions? [N.B. The ratio of specific heats for Ne is 5/3.] [12]

(d) If the gas in part (c) were N_2 rather than Ne, what factor(s) in the calculation would be different? Explain your answer. [4]

C3 (a) Show that the Bragg condition for the reflection of x-rays of wavelength λ from crystal planes whose spacing is d is

$$2d \sin\theta = n\lambda \ ,$$

where θ is the angle between the incident direction and the crystal plane, and n is an integer. [10]

(b) X-rays of wavelength 0.20 nm are reflected from a NaCl crystal; the first order maximum occurs at 15.5°. What value does this give for the inter-planar spacing of NaCl? [8]

(c) X-rays of wavelength 0.10 nm are used instead.

i. At what angle is the first peak observed? [4]

ii. How many reflections are potentially observable? Explain your answer. [8]

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C4 (a) The radius, R, of an atomic nucleus of atomic number [illegible] given, to a good degree of accuracy, by

$$R = 1.2 \times 10^{-15}\ A^{\frac{1}{3}}\ \text{m}\ ;$$

calculate the radius of a $^{212}_{84}\text{Po}$ nucleus. [5]

(b) An α particle ($^{4}_{2}\text{He}$) is confined in a $^{212}_{84}\text{Po}$ nucleus. Assuming non-relativistic mechanics, what is the uncertainty, Δv, in the velocity of the α particle? [10]

(c) If its actual speed inside the nucleus, v, is the same as Δv, what is the kinetic energy of the α particle, in MeV? [5]

(d) The $^{212}_{84}\text{Po}$ nucleus undergoes α decay, as follows:

$$^{212}_{84}\text{Po} \rightarrow {}^{208}_{82}\text{Pb} + \alpha\ .$$

Work out the Coulomb potential energy, in MeV, of the α particle in the electric field of the $^{208}_{82}\text{Pb}$ nucleus at the edge of the nucleus. [Assume that the $^{208}_{82}\text{Pb}$ nucleus is the same size as the $^{212}_{84}\text{Po}$ nucleus, and that the dimensions of the α particle are negligible.] [6]

(e) By how much does the kinetic energy of the α particle fall short of breaking away from the Pb nucleus? [2]

(f) How can the decay still occur? [2]