KEELE UNIVERSITY

LEVEL 1 EXAMINATIONS, 2009

Level 1 (PRINCIPAL COURSE)

FRIDAY 16TH JANUARY 2009, 16.00–18.00

PHYSICS/ASTROPHYSICS

MODULE PHY-10011

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 an answer book 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. Tables of physical and mathematical data may be obtained from the invigilator.

Registration Number ....

A		C1		Total
B		C2		
		C3		
		C4		

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

A1 The absolute temperature of an ideal gas is a measure of

- ☐ the mean molecular mass of the molecules in the gas
- ☐ the average kinetic energy of the molecules in the gas
- ☐ the mean velocity of the molecules in the gas
- ☐ the specific heat of the gas [1]

A2 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]

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 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]

A5 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]

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A6 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]

A7 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
- ☐ tri-atomic gases (such as CO_2) are found
- ☐ a solid can exist in three different crystalline forms [1]

A8 Which of the following is true for the molar specific heat at constant pressure, C_p, and the molar specific heat at constant volume, C_v, of a monatomic gas:

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

A9 Hydrogen atoms in the interstellar gas display

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

A10 The energy of a photon is, in the usual notation,

☐ hf ☐ hp ☐ h/p ☐ p/h [1]

A11 ^{12}C and ^{13}C are both isotopes of carbon 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 nucleons in the nucleus [1]

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A12 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]

A13 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]

A14 The 'dimensions' of an atom are typically

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

A15 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
- ☐ depends on the nature of the surface [1]

A16 Which of the following indicate the photon (i.e. 'particle') nature of electromagnetic radiation?

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

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PART B ANSWER ALL EIGHT QUESTIONS

B1 How many ^{4}He atoms are there in a vessel that contains 20 g of ^{4}He? [3]

B2 For a sample of gas, the difference in the heat capacities at constant pressure and at constant volume $C_\mathrm{p} - C_\mathrm{v} = 34.8\,\mathrm{J\,K^{-1}}$. Find (a) the number of moles, (b) the heat capacity at constant pressure given that the gas is monatomic. [3]

B3 Sketch the temperature-dependence of the specific heat at constant volume, C_v, for a solid. Label the essential features of the plot. [3]

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B4 The van der Waals equation of state is

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

Sketch the phase diagram (i.e. P against V) for a 'real' (as opposed to 'ideal') gas that obeys the van der Waals equation of state; your sketch should include a $P - V$ curve for temperatures well below, and well above, the critical temperature T_c. [3]

B5 The density of solid arsenic is $5730\,\mathrm{kg\,m^{-3}}$. Estimate the distance between arsenic atoms in a piece of solid arsenic. [3]

B6 What is the de Broglie wavelength associated with a neutron which has kinetic energy $5\,\mathrm{keV}$? [3]

B7 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]

B8 A radio transmitter with power 3000 W transmits at frequency 500 MHz. How many photons are emitted per second? [3]

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PART C ANSWER TWO OUT OF FOUR QUESTIONS

C1. (a) In the context of Kinetic Theory, what is meant by the term *degree of freedom*? [3]

(b) What is the theorem of Equipartition of Energy? [3]

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

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

(e) Sketch the temperature-dependence of the specific heat at constant volume for (i) a monatomic gas and (ii) a diatomic gas. Label the essential features of the plot in each case. [8]

C2. (a) What is meant by an *adiabatic process*? [3]

(b) How are pressure and volume related for an adiabatic change? [3]

(c) Neon gas, at an initial temperature of 20° C and 1 atmosphere pressure, is compressed adiabatically to one-sixth its initial volume. Assuming that the ratio of specific heats for neon is $\gamma = 5/3$, determine the pressure and temperature of the gas following compression. [2×5]

(d) If the compression in part (c) had been performed isothermally rather than adiabatically, what would the pressure and temperature following compression be, assuming that the gas had the same initial conditions? [2×5]

(e) If the gas in parts (c) and (d) had been O_2 rather than Ne, what factor(s) in the calculation would have been different? [4]

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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 0.158 nm are reflected from a cubic CsCl crystal; the first order reflection occurs at 15.7°. What value does this give for the inter-planar spacing of CsCl? [4]

(c) How many other (higher) orders can in principle be observed using X-rays of this wavelength? [8]

(d) X-rays having twice the energy are reflected from CsCl; at what angle is the first order reflection seen? [8]

C4. (a) The radius, R, of an atomic nucleus of atomic number A is given, to a good degree of accuracy, by

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

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

(b) An α particle ($^4_2\mathrm{He}$) is confined in a $^{212}_{84}\mathrm{Po}$ 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 $^{212}_{84}\mathrm{Po}$ nucleus undergoes α decay, as follows:

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

Work out the Coulomb potential energy, in MeV, of the α particle in the electric field of the $^{208}_{82}\mathrm{Pb}$ nucleus *just after* it has left the Pb nucleus. [Assume that the $^{208}_{82}\mathrm{Pb}$ nucleus is the same size as the $^{212}_{84}\mathrm{Po}$ 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? [4]