UNIVERSITY OF DUBLIN

TRINITY COLLEGE

FACULTY OF ENGINEERING, MATHEMATICS & SCIENCE

SCHOOL OF PHYSICS

Junior Freshman
Annual Examination

Trinity Term 2015

Physics, Paper 2

(Science (Physics), Nanoscience Physics and Chemistry of Advanced Materials, Chemistry with Molecular Modelling and Theoretical Physics)

Wednesday 6th May 2015 RDS 9:30 – 12:30

Professors W Blau, G Cross and S Hutzler

ALL QUESTIONS CARRY EQUAL MARKS

USE SEPARATE ANSWER BOOKS FOR EACH SECTION

Log tables (Booklet of Formulae and Tables) are available from the invigilator for all students who require them. Graph paper is also available.

Non-programmable calculators are permitted for this examination – please indicate the make and model of your calculator on each answer book used.

All Students

Answer ***SIX*** questions, AT LEAST **TWO** from Section A, AT LEAST **TWO** from Section B, AT LEAST ONE from Section C AND ONE OTHER, in 3 hours.

SECTION A

1. How is the translational kinetic energy of an atom related to the temperature T?

[3 Marks]

How fast is a typical air molecule moving? Assume that a typical air molecule has a mass of 30 m_p.

[7 Marks]

2 . A block of ice, of mass 1.0 kg and initial temperature −20°C is heated until it melts, and the water is then heated until it boils, and boiled dry.

(a) How much heat is needed to heat the ice to 0°C?

[2 Marks]

(b) How much heat is needed to melt the ice?

[2 Marks]

(c) How much heat is needed to raise the water to boiling point?

[2 Marks]

(d) How much heat is needed to boil the water completely?

[2 Marks]

(e) Why does boiling need so much heat? Where does this energy go?

[2 Marks}

Specific heat of ice = 2040 J/kg·K - Specific heat of water = 4186 J/kg·K - Specific heat of steam = 2060 J/kg·K - Density of water: ρ_{water} = 1000 kg/m^3 - Latent heat of fusion for water: $L_f = 3.34 \times 10^5$ J/kg - Latent heat of vaporisation for water: $L_v = 2.26 \times 10^6$ J/kg

3. State the Ideal Gas Equation,

[3 Marks]

Exactly 1 mol of Helium gas has an internal energy of 3600 J. It is contained within a cube of sides 0.5 m.

Compare Helium under these conditions with air at standard temperature and pressure (STP).

[3 Marks]

Particularly, give comparative values for number density, pressure and temperature.

[2 Marks each]

4.

State the First Law of Thermodynamics and define all its parameters,.

[3 Marks]

A bag of sand of mass m=50 kg at a temperature of T=300 K falls from a height of h=1 m onto the ground and comes to an abrupt stop.

(a) What kind of dissipative work is done on the sand? What is its amount?

[2 Marks]

(b) What is the change in internal energy ΔU of the sand?

[2 Marks]

(c) Give an estimate of the temperature rise in the sand.

[3 Marks]

SECTION B

EQUATION LIST:

$$F=\frac{1}{4\pi\varepsilon_0}\frac{|q_1q_2|}{r^2}, \qquad \vec{E}=\frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}, \quad \vec{\tau}=\vec{p}\times\vec{E}, \quad \Phi_E=\oint\vec{E}\cdot d\vec{A}=\frac{Q_{encl}}{\varepsilon_0}$$

$$V=\frac{U}{q_0}=\frac{1}{4\pi\varepsilon_0}\frac{q}{r}, \quad V_a-V_b=\int_a^b\vec{E}\cdot d\vec{l}=\int_a^b E\cos\phi\, dl$$

$$C=\frac{Q}{V_{ab}}=\varepsilon_0\frac{A}{d}, \quad C=\frac{Q}{V_{ab}}=\varepsilon_0\frac{A}{d}$$

$$I=\frac{dQ}{dt}=n|q|v_dA, \quad R=\frac{\rho L}{A}, \quad P=V_{ab}I=I^2R=\frac{V_{ab}^2}{R}$$

$$q=C\mathcal{E}\left(1-e^{-t/RC}\right)=Q_f\left(1-e^{-t/RC}\right)$$

$$\vec{F}=q\vec{v}\times\vec{B}, \quad \Phi_B=\int B_\perp\, dA=\int B\cos\phi\, dA=\int\vec{B}\cdot d\vec{A}, \quad \vec{F}=I\vec{l}\times\vec{B}, \quad \vec{\tau}=\vec{\mu}\times\vec{B}$$

$$\vec{B}=\frac{\mu_0}{4\pi}\frac{q\vec{v}\times\hat{r}}{r^2}, \quad d\vec{B}=\frac{\mu_0}{4\pi}\frac{I\, d\vec{l}\times\hat{r}}{r^2}, \quad B_x=\frac{\mu_0NI}{2a}, \quad \oint\vec{B}\cdot d\vec{l}=\mu_0 I_{encl}$$

$$\mathcal{E}=-\frac{d\Phi_B}{dt}, \quad \mathcal{E}=\oint(\vec{v}\times\vec{B})\cdot d\vec{l}, \quad \oint\vec{E}\cdot d\vec{l}=-\frac{d\Phi_B}{dt}$$

5.

(a) State Gauss's Law in words and formula.

[2 marks]

(b) Explain with a diagram why the electric field must be perpendicular to the surface of a conductor.

[3 marks]

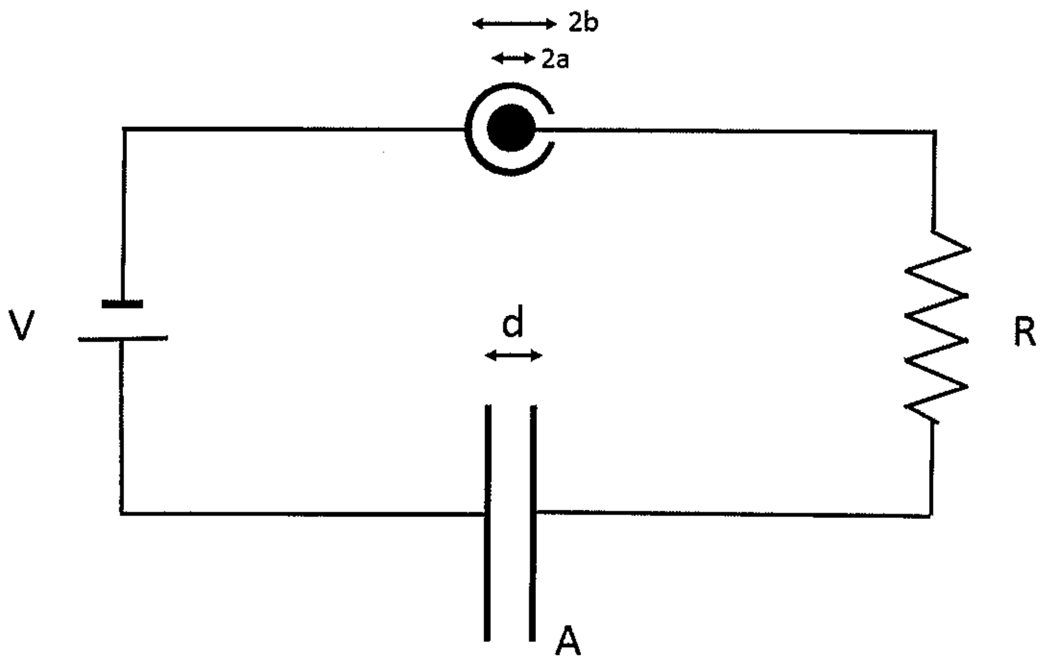
(c) An insulating sphere with radius R has a uniform charge density ρ . Find the electric field vector inside and outside of the sphere if it has dielectric constant K.

[3 marks]

(d) Suppose the same sphere had a spherical hole made in it of radius a centered a distance b from the center, where $a<b<a+b<R$. Find $\vec{\mathbf{E}}$ (electric field magnitude and direction) inside the hole. Show that it is uniform everywhere. (Hint: show that in general $\vec{\mathbf{E}}=\rho(\vec{\mathbf{r}}-\vec{\mathbf{b}})/3\varepsilon$ for a sphere as in (c) but displaced from the origin by $\vec{\mathbf{b}}$, then use superposition.)

[3 marks]

6..



A circuit is to be constructed consisting of a source of *emf* V, a resistor R , wired to two capacitors as shown above. The upper capacitor consists of a thin, conducting spherical shell of diameter $2b$ concentric to a conducting spherical sphere of diameter $2a$. The lower capacitor is a conventional parallel plate each with area A separated by distance d . Both are filled with a dielectric with permittivity ε .

(a) What is the capacitance of the parallel place capacitor?

[1 mark]

(b) What is the capacitance of the spherical capacitor? (Hint: ignore the wires and the small opening in the shell for the wire connected to the sphere. Note the figure only shows a cross-section: the electrodes are fully spherical.)

[3 marks]

(c) What is the charge that builds up on the capacitors after a long time?

[2 marks]

(d) How long does it take to charge the combined capacitance to 90%?

[3 marks]

(e) What is the current through R at the 90% charge time of (b)?

[1 mark]

7. A square shaped coil of N turns has dimensions a height and b width. The coil is placed in a uniform magnetic field of strength $\vec{\mathbf{B}}$ and fixed in a way so that it can rotate about an axis parallel to its width running through its center. The area vector $\vec{\mathbf{A}}$ of the coil initially makes an angle φ with respect to $\vec{\mathbf{B}}$.

(a) If a current I is supplied, what is the magnetic moment vector $\vec{\boldsymbol{\mu}}$ of the coil?

[4 marks]

(b) What is the magnitude and direction of the torque generated on the coil?

[3 marks]

(c) Sketch a picture of the coil in positions of stable and unstable equilibrium with respect to the magnetic field.

[1 mark]

(d) How much work must be done to bring the coil from the stable to unstable equilibrium point?

[2 Marks]

8. Magnetic field of a wire

(a) State Ampere's Law in words and formula.

[2 marks]

(b) Consider a straight, long wire of diameter $2a$ with a uniform current density $\vec{\mathbf{J}}$ throughout pointing along its axis. Find the magnetic field $\vec{\mathbf{B}}$ (magnitude and direction) both inside and outside the wire.

[5 marks]

(c) If the current of (b) was instead found only on the surface of the wire, find the magnetic field $\vec{\mathbf{B}}$ (magnitude and direction) both inside and outside the wire.

[3 marks]

SECTION C

9.

(a) What is the Compton effect? Refer to the relevant symbols in the equation $\lambda' - \lambda = \frac{h}{mc}(1 - \cos\theta)$. What is the relevance of the Compton effect in the history of modern physics?

[3 marks]

(b) X-rays having an energy of 300 keV undergo Compton scattering from a target. The scattered rays are detected at 37^{o} relative to the incident rays. Find the Compton shift at this angle. What is the energy of the scattered X-rays? What is the energy of the recoiling electron?

[5 marks]

(c) Is the Compton effect noticeable in an experiment using visible light? Explain your answer.

[2 marks]

10.

(a) A 75-W light source consumes 75 Watt of electrical power. Assume all this energy goes into emitted light of wavelength 600 nm. Calculate the frequency of the emitted light.

[1 mark]

(b) How many photons per second does the above source emit?

[3 marks]

(c) Is the frequency of the light the same thing as the number of photons emitted per second? Explain.

[2 marks]

(d) The human eye is most sensitive to green light of wavelength 505 nm. Experiments have found that when people are kept in a dark room until their eyes adapt to the darkness, a *single* photon of green light will trigger receptor cells in the rods of the retina. To appreciate the smallness of the amount of energy delivered to the receptor cells calculate how fast a typical bacterium of mass 9.5×10^{-12} g would move if it had that much energy.

[4 marks]

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Electron rest mass	m_e	9.11×10^{-31} kg
Proton rest mass	m_p	1.67×10^{-27} kg
Electronic charge	e	1.60×10^{-19} C
Speed of light in free space	c	3.00×10^{8} m s^{-1}
Planck's constant	h	6.63×10^{-34} J s
	$h/2\pi = \hbar$	1.05×10^{-34} J s
Boltzmann's constant	k	1.38×10^{-23} J K^{-1}
Molar gas constant	R	8.31×10^{3} JK^{-1}kmol^{-1}
Avogadro's number	N_A	6.02×10^{26} kmol^{-1} $= 6.02 \times 10^{23}$ mol^{-1}
Standard molar volume		22.4×10^{-3} m^3
Bohr magneton	μ_B	9.27×10^{-24} A m^2 OR J T^{-1}
Nuclear magneton	μ_N	5.05×10^{-27} A m^2 OR J T^{-1}
Bohr radius	a_o	5.29×10^{-11} m
Fine structure constant		
	$e^2/(4\pi\varepsilon_o\hbar c) = \alpha$	$(137)^{-1}$
Rydberg's constant	R_∞	1.10×10^{7} m^{-1}
Stefan's constant	σ	5.67×10^{-8} W m^{-2} K^{-4}
Gravitational constant	G	6.67×10^{-11} N m^2 kg^{-2}
Proton magnetic moment	μ_p	$2.79\ \mu_N$
Neutron magnetic moment	μ_n	$-1.91\ \mu_N$
Permeability of free space	μ_o	$4\pi \times 10^{-7}$ H m^{-1}
Permittivity of free space	ε_o	8.85×10^{-12} F m^{-1}
1 electron volt	eV	1.60×10^{-19} J
1 unified atomic mass unit (^{12}C scale)		1.66×10^{-27} kg = 931 MeV/c^2
Wavelength of 1 eV photon		1.24×10^{-6} m
1 atmosphere		1.01×10^{5} N m^{-2}

Standard acceleration due to gravity		$10\ m\ s^{-2}$
Free space impedance	Z_0	$377\ \Omega$
Astronomical unit	au	1.50×10^{11} m
Parsec	pc	3.09×10^{16} m
Solar radius	$R_\odot$	6.96×10^{8} m
Solar mass	$M_\odot$	1.99×10^{30} kg
Solar luminosity	$L_\odot$	3.85×10^{26} W
Earth mass	$M_\oplus$	5.97×10^{24} kg
Earth radius (equatorial)	$R_\oplus$	6378 km