XPY1P201

UNIVERSITY OF DUBLIN

TRINITY COLLEGE

FACULTY OF ENGINEERING, MATHEMATICS & SCIENCE

SCHOOL OF PHYSICS

Junior Freshman Trinity Term 2013

Annual Examination

Physics, Paper 2

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

Saturday 11th May 2013 RDS 09.30 – 12.30

Professors W. Blau, G. Cross and S. Hutzler

ALL QUESTIONS CARRY EQUAL MARKS.

USE SEPARATE ANSWER BOOKS FOR EACH SECTION

Both old log tables (Mathematics Tables) and new 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. (a) Define the average kinetic energy of an atom in terms of temperature.

[4 marks]

(b) At what temperature is the average kinetic energy per atom of Neon gas equal to the kinetic energy of a singly charged Neon ion that has been accelerated through a potential difference of 5 Volts?

[6 marks]

2. (a) State the molar heat capacities C_V and C_p of an ideal gas.

[4 marks]

(b) Find the molar mass and the number of degrees of freedom of molecules in a gas if its heat capacities are known: C_v = 650 J/(kg*K) and C_p = 910 J/(kg*K).

[6 marks]

3. (a) Briefly derive an expression for the internal energy of an ideal gas from kinetic gas theory.

[4 marks]

(b) Demonstrate that the internal energy U of the air in a room is independent of temperature provided the outside pressure p is constant. Calculate U, if p is equal to the normal atmospheric pressure and the room's volume is equal to $V = 40\ m^3$.

[6 marks]

4. An ideal gas of molar mass M is located in the uniform gravitational field in which the acceleration due to gravity is equal to g. Find the gas pressure as a function of height h, if $p = p_0$ at $h = 0$, and the temperature varies with height as

(a) $T = T_0\,(1 - a h)$;

[5 marks]

(b) $T = T_0\,(1 + a h)$,

[5 marks]

where a is a positive constant.

SECTION B

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

[1 mark]

(b) Consider an insulating sphere of radius R with a uniform positive charge density ρ throughout. Find an expression for the electric field vector as a function of radial distance from the centre of the sphere, both inside and outside the sphere.

[4 marks]

(c) What is the electric field at the centre of the sphere?

[1 marks]

(d) Calculate the electric potential inside and outside the sphere.

[3 marks]

(e) If the insulating sphere was coated by a thick shell of metal, what would the charge at the outer surface of the metal be?

[1 marks]

6. (a) Discuss the difference between the drift velocity in a current carrying wire and individual electron velocity, and why this difference exists.

[1 mark]

(b) You are to construct a circular capacitor with a dielectric sheet of thickness *1 mm* and dielectric constant K=2.2. For a $12\,pF$ capacitor, what radius of dielectric sheet is required?

[4 marks]

(c) The capacitor you have made is charged to 1 μC. What is the voltage across the plates?

[2 marks]

(d) Now you discharge the capacitor through a resistor. If it takes 200 ns to discharge to one half the voltage, what is the value of the resistor?

[3 marks]

Equation List

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

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

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

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

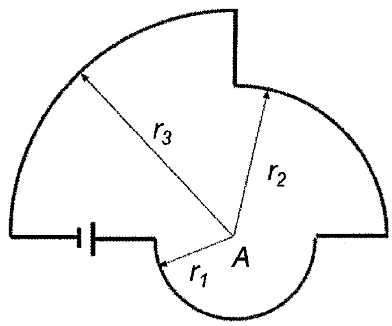
$$q=C\mathcal{E}\left(1-e^{-t/RC}\right)=Q_f\left(1-e^{-t/RC}\right)$$

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

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

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

7. The circuit pictured below consists of three circular arcs with radii $r_3=3r_1$, $r_2=2r_1$, and r_1 connected by radial paths all concentric to point A. If the total resistance of the wire is $R=2\Omega$ and a heavy-duty battery of voltage $V=15V$ is connected as shown, what is the magnitude and direction of the magnetic field at A if $r_1=5m$?

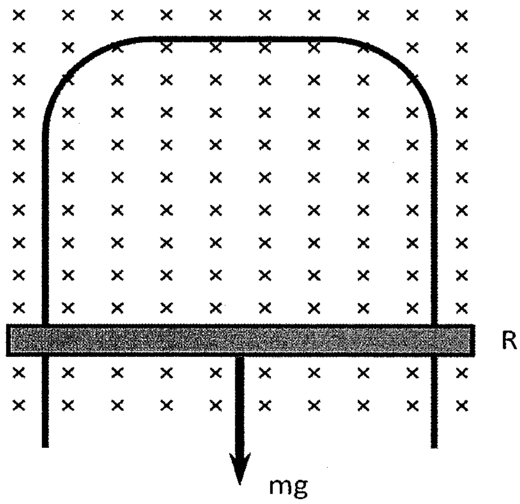


[10 marks]

8. (a) State Faraday's law in words and the meaning of the variables in its equation form

[2 marks]

(b) A conducting slide-wire system is setup as shown below. The sliding wire (grey) has mass m and electrical resistance R and falls under gravity as shown. The fixed wire loop has zero resistance and lies perpendicular to a uniform magnetic field B shown pointing into the page. Use Faraday's law to determine the maximum velocity of the slide wire.



[6 marks]

(c) How much power is dissipated at the peak velocity?

[2 marks]

SECTION C

9. The law of radioactive decay is given by $N(t)=N_0 \exp(-\lambda t)$, where N_0 is the number of particles at time $t=0$, $N(t)$ is the number at time t, and λ is the decay constant.

(a) Derive an expression for the half life $T_{1/2}$.

[3 marks]

(b) The radioactive isotope ^{57}Co decays with a half-life of 272 days. Find its decay constant.

[2 marks]

(c) If you have a radiation source containing ^{57}Co, with activity of 74000 Becquerel, how many radioactive nuclei does it contain?

[2 marks]

(d) What will be the activity of your source after one year?

[3 marks]

10. (a) Determine the wavelength of an electron that has been accelerated through a potential difference of 100V. (use for mass of electron: $m_e=9.11\times10^{-31}\ kg$)

[3 marks]

(b) Calculate the de Broglie wave-length of a 5 g bullet that is moving at the speed of sound. Can the bullet exhibit wavelike properties? Can the electron above? Justify your answers.

[4 marks]

(c) Is light a particle or a wave? Justify your answer

[3 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 <u>OR</u> J T^{-1}
Nuclear magneton	μ_N	5.05×10^{-27} A m^2 <u>OR</u> 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_o		377 Ω

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