UNIVERSITY OF DUBLIN

TRINITY COLLEGE

FACULTY OF ENGINEERING, MATHEMATICS & SCIENCE

SCHOOL OF PHYSICS

Junior Freshman
Annual Examination

Trinity Term 2014

Physics, Paper 2

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

Saturday 10^{th} May 2014 | Luce Upper | 09:30 – 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) A 300 W electric immersion heater is used to heat a cup of water. The cup is made of glass and its mass is 300 g. It contains 250 g of water at 15°C. How much time is needed to bring the water to the boiling point? Assume that the temperature of the cup is the same as the temperature of the water at all times and that no heat is lost to the air.

(Specific heat of glass: 664 J kg^{-1} K^{-1}; specific heat of water: 4180 J kg^{-1} K^{-1})

[10 marks]

2) A 750 kg car, moving at 83 kph, brakes to a stop. The brakes contain about 15 kg of iron, which absorbs the energy. What is the increase in temperature of the brakes?
(Specific heat of iron: 450 J kg^{-1} K^{-1})

[10 Marks]

3) How many particles are in one cubic centimetre of air at standard pressure and 293 K?

[4 marks]

Physicists can, with proper equipment, obtain vacuums with pressures of 10^{-11} Torr.
What fraction of atmospheric pressure is this?

[2 marks]

Find the number of particles in a cubic centimetre of this vacuum.

[4 marks]

4) A very tall vertical cylinder contains a gas at a temperature T. Assuming the gravitational field to be uniform, find the mean value of the potential energy of the gas molecules.

[8 marks]

Does this value depend on whether the gas consists of one kind of molecules or of several kinds?

[2 marks]

SECTION B

5)

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

[2 marks]

b) A long cylinder of radius a and length $L > a$ has a charge $+Q$ uniformly distributed throughout its volume. The cylinder is fixed along the interior axis of a conducting cylindrical shell of inner radius $b > a$, outer radius $c > b$ and length L. Find expressions for the electric field vector as a function of radial distance from the interior axis of the concentric cylinders, eg. For inside the first cylinder, between the two cylinders, inside the conducting cylinder, and outside the conducting cylinder. Be sure to draw a diagram of the setup.

[4 marks]

c) What is the surface charge density on the outside of the conducting cylinder?

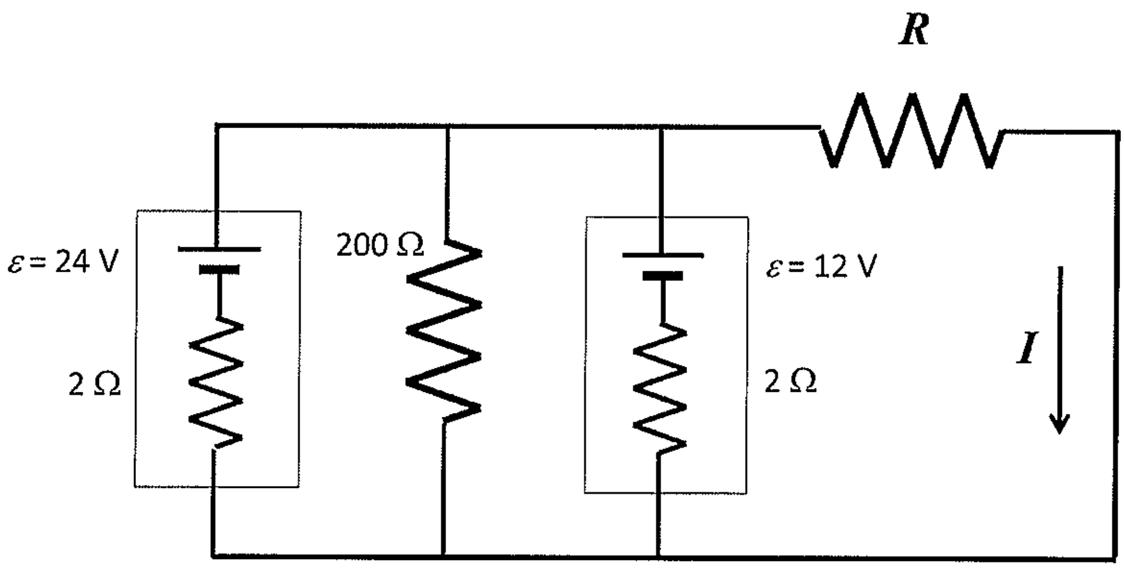
[1 mark]

d) Find the electric potential at all radial locations

[3 marks]

6) Circuits

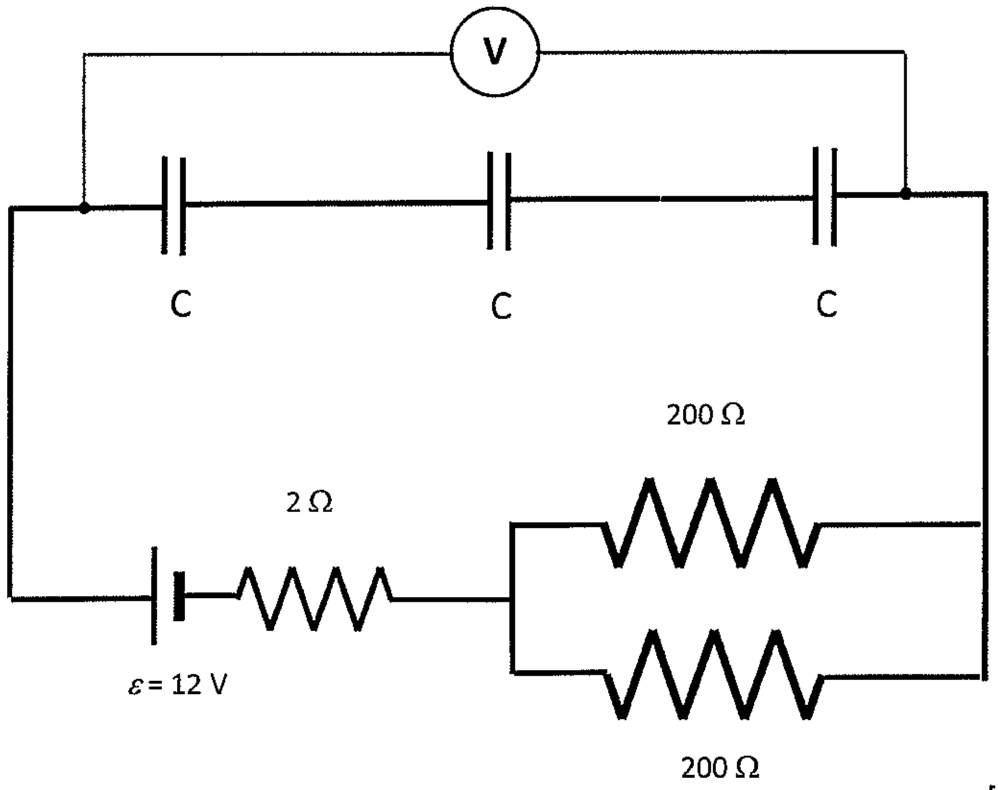
a) For the circuit below, find the value of the resistor R such that the current $I = 100mA$



[4 marks]

b) In the circuit shown below, three air-gap capacitors of capacitance C each are wired together in series together with a 12 V battery with internal resistance of 2Ω and two resistors in parallel. It is noted, as the last wire is attached, that the voltage V across the three capacitors reaches 10 V in 0.1 ms. What is the value of C?

NOTE: Question 6 continued on next page



[4 marks]

c) How much time would it take voltage across the capacitors to reach 10 V during charging if the air gaps between the capacitor plates were replaced by plastic with a dielectric constant of $K = 3$?

[2 marks]

Equation List

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

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

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

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

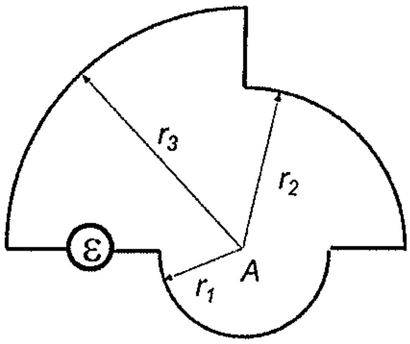
$$q=C\mathcal{E}\left(1-e^{-t/RC}\right)=Q_{\text{f}}\left(1-e^{-t/RC}\right)$$

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

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

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

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, where $r_1 = 2m$. If the resitivity of the ohmic wire is $\rho = 2\times10^{-8}\ \Omega m$ and has a cross-sectional area of $1mm^2$, what is the magnitude and polarity of the EMF source ε if the magnetic field at A is $1.0\times10^{-7}T$ pointing out of the page?



[10 marks]

8)

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

[2 marks]

b) A simple hydroelectric power generator is constructed such that the flow of a small stream turns rotates a square loop of wire of length $l = 1m$ on each side once per second. The loop is placed in a constant magnetic field with strength $B = 1T$. How much energy is generated per day from the power station if the loop resistance is $R = 1\Omega$?

[6 marks]

c) What would happen to the daily energy output if a longer piece of the same wire coiled into 10 loops of the same area was used instead?

[2 marks]

SECTION C

9) The charge of an electron was first measured by Robert Millikan. Oil (density ρ) is sprayed in very fine drops of radius r into the air-filled space between two parallel horizontal plates, separated by a distance d. An electrical potential difference U is maintained between the plates, causing a downward electric field between them. Some of the oil drops acquire an (initially unknown) negative charge q because of frictional or other effects.

a) Show that the observation (using a microscope) of a static drop allows a determination of its charge by deriving the relevant equation (assume that the drop radius is known).

[4 marks]

b) Cutting off the electric field, the drop radius can be computed from the experimental determination of the terminal speed v that the drop acquires when moving through a viscous medium. Determine r using Stokes law for the viscous force, $F=6\pi\eta rv$ (η is the viscosity of air). Use the equation for r to express the magnitude of the charge of the drop in terms of its terminal speed and the other known quantities.

[4 marks]

c) What values for q did Millikan find in the experiment?

[2 marks]

10)

a) Briefly describe three distinct pieces of evidence, as were known by the beginning of the 20th century, which supported the idea that matter is made up of atoms.

[6 marks]

b) Briefly discuss what is meant by particle-wave duality.

[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} = 6.02×10^{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 μ_N
Neutron magnetic moment	μ_n	-1.91 μ_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 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