Coláiste na Tríonóide, Baile Átha Cliath
Trinity College Dublin
Ollscoil Átha Cliath | The University of Dublin

FACULTY OF ENGINEERING, MATHEMATICS & SCIENCE

SCHOOL OF PHYSICS

Junior Fresh Trinity Term 2018

Annual Examination

X-PY1P20-1

Physics, Paper 2

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

Friday 11 May 2018 RDS 09:30 – 12:30

Professors P. Gallagher, J. Groh and J. Pethica

ALL QUESTIONS CARRY EQUAL MARKS

USE SEPARATE ANSWER BOOKS FOR EACH SECTION

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

EQUATION LIST:

$$F = \frac{1}{4\pi\varepsilon_0}\frac{|q_1 q_2|}{r^2}, \qquad \vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}, \ \vec{\tau} = \vec{p}\times\vec{E}, \ \Phi_E = \oint \vec{E}\cdot d\vec{A} = \frac{Q_{\text{encl}}}{\varepsilon_0}$$

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

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

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

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

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

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

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

SECTION A

1.

(a) Describe the main structural components of the Milky Way Galaxy, using a diagram to illustrate your answer.

[3 marks]

(b) How can 21 cm Hydrogen line observations be used to estimate the velocities and directions of motion of spiral arms in the Milky Way? Use diagrams to illustrate your answer.

[3 marks]

(c) A radio telescope was used to measure 21 cm (1420.406 MHz) line emission from a spiral arm of the Milky Way to be shifted 1419.98 MHz. Using the Doppler formula, calculate the corresponding velocity.

[3 marks]

What other effects should be taken into account to calculate the velocity relative to the local standard of rest?

[1 mark]

2.

(a) The brightness of stars can be described using

- **i)** apparent magnitude,
- **ii)** absolute magnitude and
- **iii)** luminosity.

Define each of these measures.

[3 marks]

(b) The star Rigel is at a distance of 237 pc and has an apparent magnitude of 0.12. What is its absolute magnitude?

[2 marks]

(c) Describe how stellar spectra can be used to classify stars into a spectral type. Use this scale to sketch the Hertzsprung-Russell diagram, showing the locations of the main sequence, red giants, blue supergiants, and white dwarfs.

[4 marks]

(d) Sketch the constellation of Orion, identifying the names of the main stars and the Orion Nebula (M42).

[1 mark]

SECTION B

3.

(a) A silver wire which is 52 cm long, with cross sectional area 0.3 cm^2, and ***resistivity*** of $\rho = 32 \times 10^{-9}\,\Omega m$ is connected to a 1.5 V power supply. What is the current density J in the wire? If the drift velocity of electron charge carriers is 0.2 mm/s, what is the density of free electrons in the wire?

[2 marks]

(b) What is the rate of heat generation in the wire? If the power supply in the circuit described in a) is changed to a 4.5V battery, what is the new rate of heat generation in the wire?

[2 marks]

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

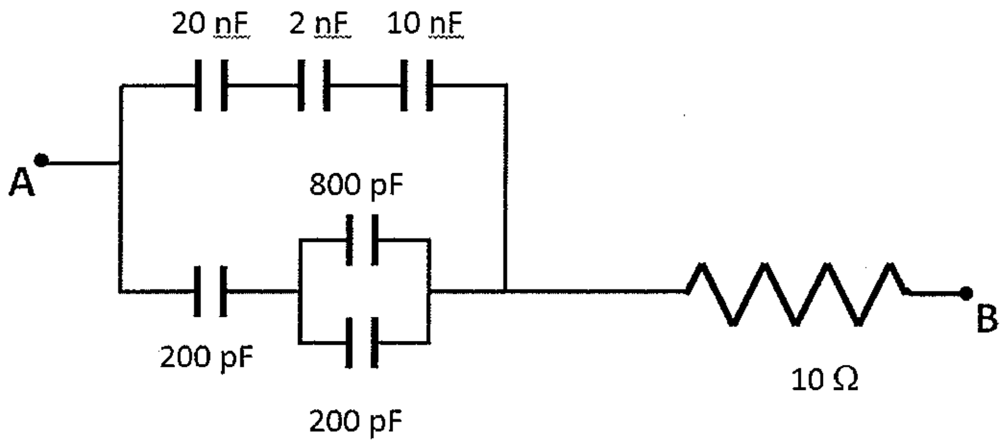
[1 mark]

(d) A parallel plate capacitor in vacuum consists of two large metal plates each of area A and thickness h separated by a small distance d. A voltage V is applied across the plates to completely charge them. Use Gauss's law to find the electric field both outside the plates and between the plates. Be sure to draw a diagram and consider and discuss all the electric flux at all regions of your Gaussian surface(s).

[5 marks]

4. Circuits

(a) What is the equivalent capacitance in the following network?

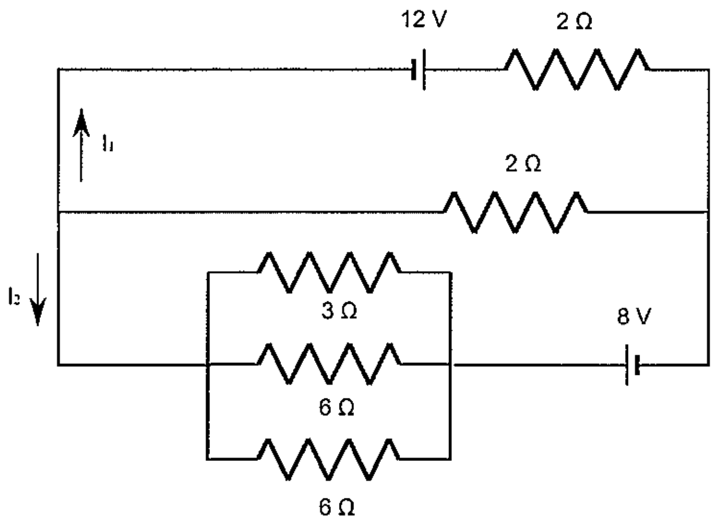


[2 marks]

(b) If 3 V is applied across points A-B, what is the charge stored in the network after 2ns?

[2 marks]

(c) Use Kirchoff's Rules to calculate the two currents shown in the circuit below.



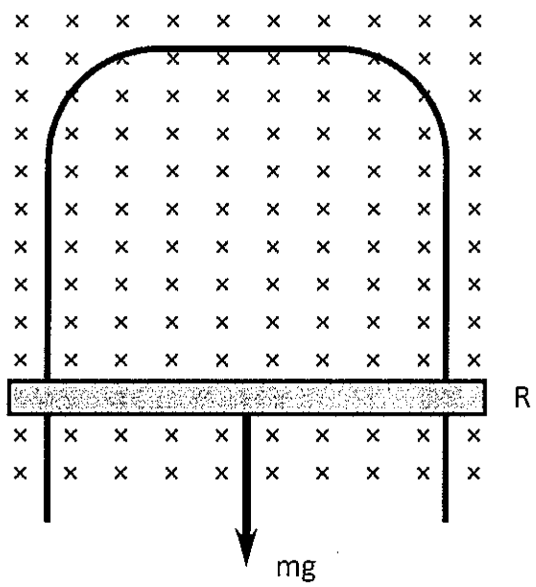
[6 marks]

5.

(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

6.

(a) What is Compton scattering? How does it show that electromagnetic waves have momentum? Describe the physical principles involved in deriving the Compton formula

$$\lambda' - \lambda = \frac{h}{m_o c}(1-\cos\phi)$$

relating change in wavelength to angle through which the wave is scattered. The full derivation is not required.

[3 marks]

An X-Ray photon having energy 200keV collides with a stationary electron and is scattered through an angle of 90 degrees. Calculate the kinetic energy of the scattered electron.

[2 marks]

(b) What is meant by the Uncertainty Principle? Give the formulae for the cases of momentum and of energy.

[2 marks]

An atomic clock uses the frequency of a photon emitted by an atomic level transition to determine time intervals. Using the uncertainty principle find an expression relating the fractional uncertainty in photon frequency to the energy and the lifetime of the transition.

If the clock is to have an accuracy of 1 part in 10^{16}, estimate the required lifetime of the transition for 1eV photons. Would use of light rather than microwaves be likely to improve the clock accuracy?

[3 marks]

7.

(a) A particle is in a 1-D box of length L with potential $U = 0$ inside the box and U infinite elsewhere. Find an expression for the normalized wavefunction inside the box which meets these boundary conditions, and show that it satisfies the Schroedinger equation

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{2m}{\hbar^2}\left(E - U\right)\psi = 0$$

[4 marks]

(b) Give the formula for the energies of the states, and sketch the three lowest energy wavefunctions.

[2 marks]

(c) What is the Pauli exclusion principle, and to what type of particles does it apply?

[2 marks]

(d) Six electrons are placed in the 1-D box and occupy the lowest energy states possible. If L = 1nm what is the minimum energy required to move an electron in the ground state up to an available empty state?

[2 marks]

8.

(a) Particles of kinetic energy E are incident on a potential step of height U where $U < E$. Find an expression for the probability of particles being reflected from the potential step, and hence the probability of electrons having E = 10eV being reflected by a step with U = 3eV

[4 marks]

Describe in outline some physical phenomena that may occur if the potential step is of finite width, for the situations $U < E$ and $U > E$.

[3 marks]

(b) The principle of equipartition of energy leads to the classical result that the specific heat of a simple solid is independent of temperature, but experimentally the specific heat is observed to fall at low temperatures. Describe how Planck's introduction of quantization of oscillator energies explains this phenomenon.

[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
	$\hbar = h/2\pi$	1.05×10^{-34} J s
Boltzmann's constant	k	1.38×10^{-23} J K^{-1}
Molar gas constant	R	8.31 J K^{-1}mol^{-1}
Avogadro's number	N_A	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	$e^2/(4\pi\varepsilon_o\hbar c)$	$(137)^{-1}$
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 (1 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}
Acceleration due to gravity	g	9.8 m s^{-2}
Free space impedance	Z_0	377 Ω

Astronomical unit (1 au)		1.50 x 10^{11} m
Parsec (1 pc)		3.09 x 10^{16} m
Solar radius	$R_\odot$	6.96 x 10^{8} m
Solar mass	$M_\odot$	1.99 x 10^{30} kg
Solar luminosity	$L_\odot$	3.85 x 10^{26} W
Earth mass	$M_\oplus$	5.97 x 10^{24} kg
Earth radius (equatorial)	$R_\oplus$	6.378 x 10^{6} m