UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

MAIN EXAMINATION 2006/2007

TITLE OF PAPER	:	**ELECTRICITY & MAGNETISM**
COURSE NUMBER	:	**P221**
TIME ALLOWED	:	**THREE HOURS**
INSTRUCTIONS	:	**ANSWER ANY FOUR OUT OF FIVE QUESTIONS**
		EACH QUESTION CARRIES 25 MARKS
		MARKS FOR DIFFERENT SECTIONS OF EACH QUESTION ARE SHOWN IN THE RIGHT-HAND MARGIN

THIS PAPER HAS 7 PAGES, INCLUDING THIS PAGE

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Physical Constants and Units

Acceleration due to gravity	g	$9.81\ \mathrm{m\ s^{-2}}$
Gravitational constant	G	$6.673 \times 10^{-11}\ \mathrm{N\ m^2\ kg^{-2}}$
Avogadro constant	N_A	$6.022 \times 10^{23}\ \mathrm{mol^{-1}}$

Note: 1 mole = 1 *gram* molecular-weight)

Ice point	T_{ice}	273.15 K
Gas constant	R	$8.314\ \mathrm{J\ K^{-1}\ mol^{-1}}$
Boltzmann constant	k, k_B	$1.381 \times 10^{-23}\ \mathrm{J\ K^{-1}} = 0.862 \times 10^{-4}\ \mathrm{eV\ K^{-1}}$
Stefan constant	σ	$5.670 \times 10^{-8}\ \mathrm{W\ m^{-2}\ K^{-4}}$
Rydberg constant	R_∞	$1.097 \times 10^{7}\ \mathrm{m^{-1}}$
	$R_\infty hc$	13.606 eV
Planck constant	h	$6.626 \times 10^{-34}\ \mathrm{J\ s} = 4.136 \times 10^{-15}\ \mathrm{eV\ s}$
$h/2\pi$	$\hbar$	$1.055 \times 10^{-34}\ \mathrm{J\ s} = 6.582 \times 10^{-16}\ \mathrm{eV\ s}$
Speed of light *in vacuo*	c	$2.998 \times 10^{8}\ \mathrm{m\ s^{-1}}$
	$\hbar c$	197.3 MeV fm
Charge of proton	e	$1.602 \times 10^{-19}\ \mathrm{C}$
Mass of electron	m_e	$9.109 \times 10^{-31}\ \mathrm{kg}$
Rest energy of electron		0.511 MeV
Mass of proton	m_p	$1.673 \times 10^{-27}\ \mathrm{kg}$
Rest energy of proton		938.3 MeV
One atomic mass unit	u	$1.66 \times 10^{-27}\ \mathrm{kg}$
Atomic mass unit energy equivalent		931.5 MeV
Electric constant	ε_0	$8.854 \times 10^{-12}\ \mathrm{F\ m^{-1}}$
Magnetic constant	μ_0	$4\pi \times 10^{-7}\ \mathrm{H\ m^{-1}}$
Bohr magneton	μ_B	$9.274 \times 10^{-24}\ \mathrm{A\ m^2\ (J\ T^{-1})}$
Nuclear magneton	μ_N	$5.051 \times 10^{-27}\ \mathrm{A\ m^2\ (J\ T^{-1})}$
Fine-structure constant	$\alpha = e^2/4\pi\varepsilon_0\hbar c$	$7.297 \times 10^{-3} = 1/137.0$
Compton wavelength of electron	$\lambda_c = h/mc$	$2.426 \times 10^{-12}\ \mathrm{m}$
Bohr radius	a_0	$5.2918 \times 10^{-11}\ \mathrm{m}$
angstrom	Å	$10^{-10}\ \mathrm{m}$
torr (mm Hg, 0°C)	torr	$133.32\ \mathrm{Pa\ (N\ m^{-2})}$
barn	b	$10^{-28}\ \mathrm{m^2}$

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Question 1

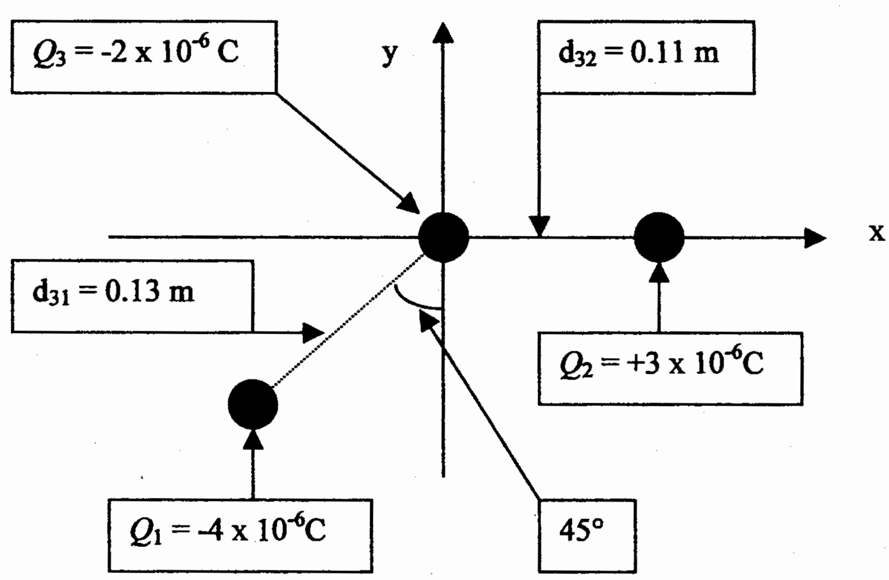
Consider a positive point charge of magnitude Q_1. What is the magnitude and direction of the electric field produced by this charge at a distance r from the charge expressed in S.I. units? [2]

What is the force that acts between two point charges of magnitudes Q_1 and Q_2? [2]

What is the principle of superposition? [3]

From the figure, determine the magnitude of the resultant force acting on Q_3 produced by charges Q_1 and Q_2. The three point charges are represented by black circles. d_{32} is the distance between point charges Q_3 and Q_2, and d_{31} is the distance between charges Q_3 and Q_1. The line connecting Q_1 and Q_3 is inclined at 45° to the horizontal and vertical axes. [12]

What angle does the resultant force make with the horizontal axis? [6]



Question 2

What is Gauss's law? In your answer write down an expression that gives the electric field E outside an arbitrary charge distribution, and explain carefully the meaning of the symbols in the expression [6]

Explain why, if there are no charges within a hollow conductor, that the field inside the conductor must be zero. [7]

Consider a cylindrical, straight, long conductor that has a surface charge density of σ C/m², and a radius of r m. The radius is much smaller than the length of the cylinder, so that "end effects" may be ignored.

What is the electric field strength at the surface of the conductor, and at a distance R from the central line of the conductor with $R > r$? [12]

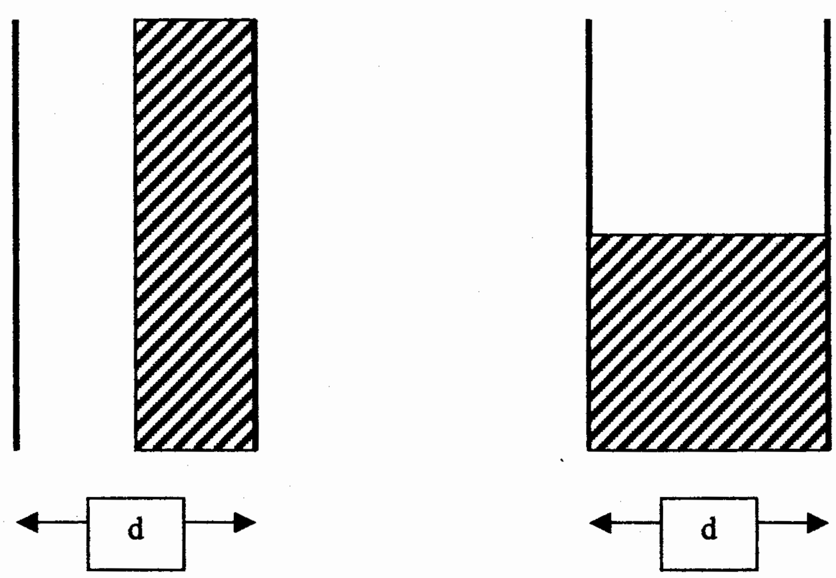
Question 3

What is the capacitance, in S.I. units, of a parallel-plate capacitor operating in air, which is made of two plates each of area A and separated by a distance d? [2]

A solid insulator is inserted between the plates. Explain why the average electric field between the plates is reduced, and the capacitance increased. [5]

It is desired to increase the capacitance of a parallel-plate capacitor by introducing material, with a relative permittivity of 5, between the plates. However, there is only enough material to fill half the space between the plates.

In the diagram, two possibilities are depicted. The dielectric is shown as the hatched region. In the left-hand part of the diagram, the dielectric occupies half the volume of the capacitor. It completely covers the area of the right-hand plate, but only extends half-way across the capacitor to the left-hand plate. In the right-hand part of the diagram, the dielectric fills the bottom half of the capacitor only. Determine, in each case, the fractional increase in the capacitance. d is the distance between the two plates of the capacitor. [18]



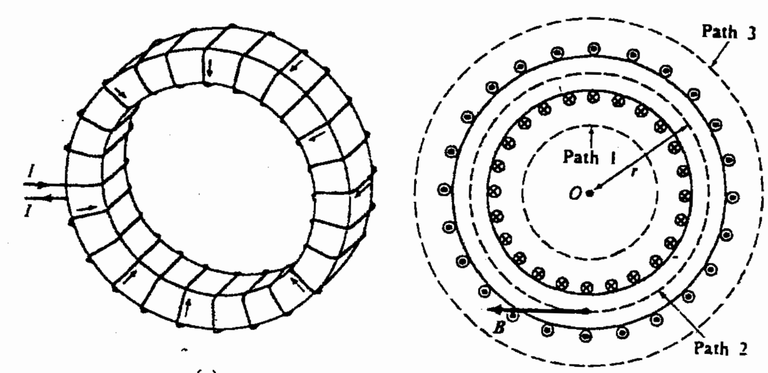
[The mark of 18 for this section will be divided in half. Evaluation of the capacitance in each of the two cases will be given equal weight].

Question 4

Write down an expression that relates the line integral of the magnetic flux density B to the current that flows through the path of the integral. [4]

A single straight wire is parallel to the z direction of a particular Cartesian co-ordinate system. Electrons carry a current of I, and their drift velocity is in the negative z direction. Draw a diagram of the magnetic flux lines produced by the flowing current, and include the direction that the flux lines circulate about the wire. [6]

The diagram (a) shows a three dimensional drawing of a toroidal coil or winding. Diagram (b) shows a cross-section through the coil. Evaluate the magnetic flux density at all points by considering the three paths shown. [15]



(a) (b)

(a) A toroidal winding. (b) Closed paths (dotted circles)

Question 5

A positively charged particle is moving in a region of space where there are crossed electric and magnetic fields – that means that the two fields are perpendicular to each other. The velocity of the positively charged particle is in the $+x$ direction and the electric field is in the $+y$ direction. In what direction should the magnetic field be applied so that the particle travels in a straight line? [6]

Evaluate the magnitude of the magnetic flux density required if the velocity of the charged particle was 10^{-6} *m/s* and the electric field strength was 500 *V/m*. [7]

An electron, starting from rest, moves unimpeded in an electric field of 100 *V/m*. Find

(a) the force it experiences
(b) its acceleration
(c) the kinetic energy it attains in moving through a potential difference of 200 *V*
(d) the velocity it has after it has moved 2 *m*. [12]