THE UNIVERSITY OF SYDNEY

FACULTIES OF ARTS, EDUCATION & SOCIAL WORK,
ENGINEERING AND SCIENCE

PHYS1004
PHYSICS 1 (ENVIRONMENTAL & LIFE SCIENCES)

NOVEMBER 2007

Time allowed: THREE Hours

MARKS FOR QUESTIONS ARE AS INDICATED
TOTAL: 90 marks

INSTRUCTIONS
• All questions are to be answered.
• Use a separate answer book for each section.
• All answers should include explanations in terms of physical principles.

DATA

Density of water \( \rho = 1.00 \times 10^3 \text{kg.m}^{-3} \)
Density of air \( \rho = 1.20 \text{kg.m}^{-3} \)
Atmospheric pressure \( 1 \text{ atm} = 1.01 \times 10^5 \text{Pa} \)
Magnitude of local gravitational field \( g = 9.81 \text{m.s}^{-2} \)
Avogadro constant \( N_A = 6.022 \times 10^{23} \text{mol}^{-1} \)
Permittivity of free space \( \varepsilon_0 = 8.854 \times 10^{-12} \text{F.m}^{-1} \)
Permeability of free space \( \mu_0 = 4\pi \times 10^{-7} \text{T.m.A}^{-1} \)
Elementary charge \( e = 1.602 \times 10^{-19} \text{C} \)
Speed of light in vacuum \( c = 2.998 \times 10^8 \text{m.s}^{-1} \)
Planck constant \( h = 6.626 \times 10^{-34} \text{J.s} \)
Rest mass of an electron \( m_e = 9.110 \times 10^{-31} \text{kg} \)
Rest mass of a neutron \( m_n = 1.675 \times 10^{-27} \text{kg} \)
Rest mass of a proton \( m_p = 1.673 \times 10^{-27} \text{kg} \)
Rest mass of a hydrogen atom \( m_H = 1.674 \times 10^{-27} \text{kg} \)
Boltzmann constant \( k = 1.381 \times 10^{-23} \text{J.K}^{-1} \)
Stefan-Boltzmann constant \( \sigma = 5.671 \times 10^{-8} \text{W.m}^{-2} \text{K}^{-4} \)
Atomic mass unit \( u = 1.661 \times 10^{-27} \text{kg} \)
Energy equivalent of 1 atomic mass unit \( E = 931.49 \text{MeV} \)
SECTION A

Question 1
a) A closed cylindrical tin can of height 0.40 m and diameter 0.30 m is evacuated using a vacuum pump.
   i. Calculate the net force acting on one end of the can after it has been evacuated.
   ii. Explain in physical terms why the can is observed to collapse. Why does it squash from the sides as well as from the top?

b) A hydraulic press consists of two interconnected cylinders filled with a liquid. It is used to lift large weights such as cars in a workshop. Explain briefly the physical principle which enables the output force of a hydraulic press to be much greater than the input force.

(5 marks)

Question 2
a) Explain why a soap bubble drifting freely in air is spherical.
b) Explain why a water droplet spreads out into a thin layer when placed on clean glass, but forms a compact bead on an oily surface.
c) The diagram below shows a small metal plate suspended on a water surface by the force of surface tension. The water surface is vertical where it touches the edge of the plate. Given that the plate is a square with dimensions of 0.050 m by 0.050 m and the surface tension of water is $7.28 \times 10^{-2}$ N.m$^{-1}$, find the mass of the plate.

(5 marks)
Question 3
A parallel plate capacitor with distance $d$ between the plates is charged by connecting it to a battery. The battery is then disconnected. If the separation between the plates is reduced to $d/2$, which of the following quantities change and by how much? Provide brief justifications for your answers.

a) The electric field $E$ between the plates.
b) The potential difference $V$ between the plates.
c) The capacitance $C$ of the capacitor.
d) The potential energy $U$ stored in the capacitor.

Question 4
In a medical cyclotron, $^1H^-$ ions (H atoms with an extra electron) are accelerated by electric fields and follow paths dictated by magnetic fields. As the energy of the ions increases, they cycle in progressively larger orbits until the electrons are stripped away and the resulting protons are deflected outwards to impact targets, with the aim of producing medical isotopes.

a) Draw a diagram and explain briefly the physics of how the cyclotron works. Your diagram should include the relative orientation of the ions’ path and the magnetic field direction.
b) Explain why the orbit of the ions becomes larger as their energy increases.
c) Protons need to reach an energy $E = 30$ MeV before striking their targets. If tritium ions ($^3H^-$) are used in the same cyclotron producing 30 MeV protons (i.e. the same magnetic field $B$ and radius $R$), what is the highest energy that the tritium ions can reach? Tritium has a mass of three times that of the proton and the same charge as a proton.

Question 5
a) The surface of the sun has a temperature of approximately 5800 K. To a good approximation, we may treat it as a blackbody. What is the wavelength of the peak intensity of the radiation produced by the sun?
b) In what part of the electromagnetic spectrum does this wavelength fall?
c) The earth’s atmosphere is transparent to this wavelength, and so a lot of the energy of incoming solar radiation is absorbed and warms the earth’s surface. If the earth’s surface can be approximated by a blackbody at room temperature (300 K), what is the wavelength of the peak intensity of the radiation emitted by the earth’s surface?
d) Briefly explain the greenhouse effect using the above information.
Question 6
A medical research facility designs a cancer treatment in which a biological molecule is selectively absorbed by cancerous cells. To diagnose and treat the cancer, specific atoms in this molecule are replaced by a radioactive isotope of the same element. The researchers have the following isotopes from which to chose:

- an alpha-emitter;
- a beta-emitter;
- a gamma-emitter.

a) Which isotope would be most suitable for the diagnosis of the cancer? In one or two sentences explain your reasoning.

b) Which isotope would be most suitable for the treatment of the cancer? In one or two sentences explain your reasoning.

c) For the diagnosis molecule in part (a), the researchers also have a choice between isotopes with half-lives of 1 microsecond, 10 minutes, or 10 million years. Which of the three isotopes would be the most suitable, and why?

(5 marks)
SECTION B
(Please use a separate book for this section)

Question 7
Fresh water is flowing at a speed of 6.00 m.s\(^{-1}\) at location A in a horizontal irrigation pipeline system as shown in the diagram (viewed from above). At point A, the pipe has a diameter of 0.150 m. The pipe divides into two pipes, each of diameter 0.060 m and the water continues into these two pipes. The absolute pressure at A is 4.00 \times 10^5 \text{ Pa}.

a) Calculate the volume flow rate at A.

b) Calculate the flow speed at B. Specify any assumptions you have made in the calculation.

c) Calculate the absolute pressure in the pipe at B. Specify any assumptions that you have made in the calculation.

d) Compare the pressure values at A and B, and give a physical explanation for any difference in the values.

(10 marks)

Question 8
A sunken ship is to be raised by attaching large flotation bags to it, and then inflating them with compressed air.

a) Draw a diagram showing all the forces on the ship after the flotation bags are inflated.

b) Assume the ship of mass of 2500 tonnes (1 tonne = 1000 kg) is constructed of steel (density = 7.80 \times 10^3 \text{ kg.m}^{-3}) and the density of seawater in which the ship lies is 1.03 \times 10^3 \text{ kg.m}^{-3}, find the volume of air which must be injected into the flotation bags in order to just lift the ship off the bottom. Specify any assumptions that you make in the calculation.

c) The ship was initially on the bottom at a water depth of 1560 m. Calculate the absolute pressure at this depth.

d) Calculate the fractional change in volume of a given sample of water at a depth of 1560 m, compared with the same sample at the surface. The bulk modulus of water is 2.0 \times 10^9 \text{ Pa}.

(10 marks)
Question 9
Circuit breakers are automatic switches that protect against dangerously large total current by opening to stop the current when it exceeds a specified safe value. Once safe conditions are re-established the switches can be reset. Given that household power circuits use a number of power points connected in parallel, consider the following situation.

In a kitchen, a 1440 W toaster, a 960 W electric kettle and a 480 W microwave oven are plugged into different power points in the same circuit and connected through an 11 A circuit breaker to the 240 V household power supply.

a) Draw a circuit diagram showing how the appliances are connected.
b) Calculate the current drawn by each appliance.
c) Find the resistance of each appliance.
d) Calculate the equivalent resistance of the three appliances when all three are turned on at the same time.
e) Calculate the total current of the three appliances when all three are turned on at the same time. Will the circuit breaker open?  

(10 marks)

Question 10
A U-shaped wire with negligible resistance is placed in a region of uniform magnetic field of magnitude $B$ such that the field direction is perpendicular to the plane of the wire. In the diagram below the magnetic field is directed into the page. A metal bar of length $L$ and resistance $R$ is placed on the wire and pulled with a constant speed $v$ as shown in the diagram.

![Circuit Diagram](image)

a) Show that the rate of change of magnetic flux through the closed loop is given by

$$\frac{d\Phi}{dt} = B L v.$$

b) Find the induced emf $\varepsilon$ and the current $I$ that flows in the loop. What is the direction of the current?
c) Find the magnetic force $F$ acting on the metal bar due to this current. What is its direction?
d) What is the work $W$ done against the magnetic force while pulling the metal bar for a distance $d$ (ignore friction)?
e) Find the power $P$ in the circuit and show that the energy dissipated in the metal bar while pulling it a distance $d$ is equal to the work done on the bar.

(10 marks)
**Question 11**
Electrons are accelerated through a potential difference of 35,000 V and collide with a molybdenum target. This produces X-rays.

a) Calculate the shortest wavelength of X-rays produced.
b) Briefly explain why no shorter wavelength is produced.
c) If the accelerating potential is reduced from 35,000 V to 30,000 V, explain what will happen to the wavelength of the shortest wavelength X-rays produced.
d) Molybdenum has an atomic number of 42. If an element with larger atomic number is used as a target, explain what will happen to the wavelength of the shortest wavelength X-rays produced.

(10 marks)

**Question 12**
The radioisotope iodine-131 has atomic number 53 and decays to xenon-131 via the \(\beta\) process. The nuclear masses of \(^{131}\text{I}\) and \(^{131}\text{Xe}\) are 130.90666 u and 130.90507 u respectively (u is atomic mass unit). The mass of an electron is 0.00055 u, and \(^{131}\text{I}\) has a half-life of 8.00 days.

a) Write down the nuclear reaction for this process.
b) What is the maximum possible kinetic energy in keV of the \(\beta\) particle?
c) The \(\beta\) particles emitted in the process are observed to have a range of energies from zero up to the maximum you calculated in part (b). What is the explanation for this?
d) The isotope \(^{131}\text{I}\) is used in the diagnosis and treatment of thyroid disorders. A patient is injected with this isotope. Assume that all the iodine is concentrated in her thyroid and that it is not eliminated from her body by excretion. What fraction of the \(^{131}\text{I}\) will remain in her thyroid after 14 days?

(10 marks)

This is the end of your questions