Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

For Examiner's Use

General Certificate of Education
June 2007
Advanced Level Examination

PHYSICS (SPECIFICATION B) **PHB5**
Unit 5 Fields and their Applications

Thursday 21 June 2007 1.30 pm to 3.30 pm

For this paper you must have:
- a calculator
- a ruler
- a pair of compasses
- a loose insert containing formulae sheets and a comprehension passage to be used for Questions 5, 6, 7 and 8.

Time allowed: 2 hours

Instructions
- Use blue or black ink or ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- Answer the questions in the spaces provided.
- Show all your working.
- Do all rough work in this book. Cross through any work you do not want to be marked.
- *Formulae Sheets* are provided as a loose insert.
- The passage for answering Questions 5, 6, 7 and 8 is provided as a loose insert. Read the passage before answering the questions.

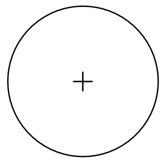
Information
- The maximum mark for this paper is 100.
- Four of these marks may be awarded for using good English, organising information clearly and using specialist vocabulary where appropriate.
- The marks for questions are shown in brackets.
- You are expected to use a calculator where appropriate.
- Questions 3(c) and 5(c) should be answered in continuous prose. In these questions you will be marked on your ability to use good English, to organise information clearly and to use specialist vocabulary where appropriate.

For Examiner's Use			
Question	Mark	Question	Mark
1			
2			
3			
4			
5			
6			
7			
8			
Total (Column 1) →			
Total (Column 2) →			
TOTAL			
Examiner's Initials			

Answer **all** questions.

1 (a) **Figure 1** and **Figure 2** show small charged metal spheres each carrying a charge Q. The potential of each sphere is 8000 V.

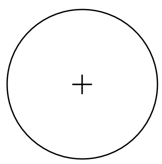
Figure 1



(i) Draw on **Figure 1** at least six lines to show the direction of the electric field in the region around the charged sphere.

(ii) Draw on **Figure 2** the equipotential lines for potentials of 4000 V and 2000 V.

Figure 2



(iii) The equation for the field strength at a distance r from the sphere is $\dfrac{Q}{4\pi\varepsilon_0 r^2}$.
State the name of the quantity represented by ε_0.

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(5 marks)

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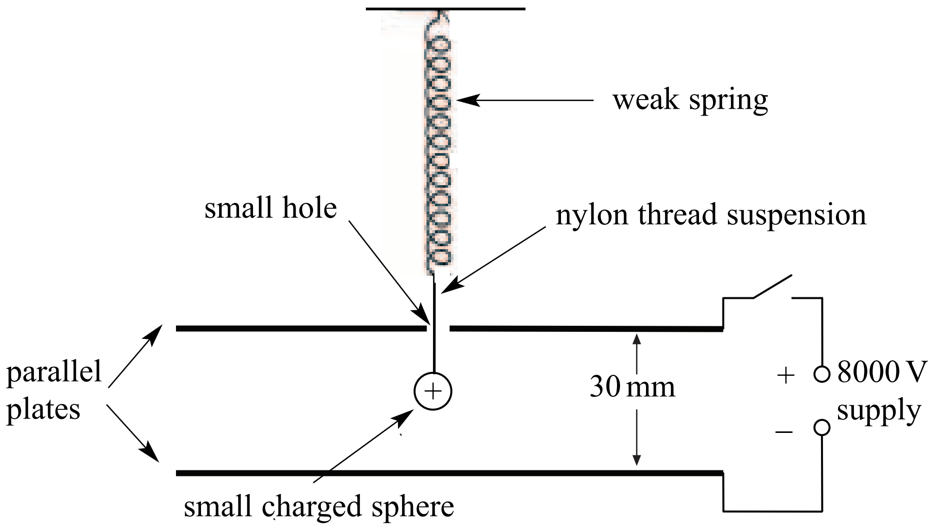
(b) **Figure 3** shows an arrangement for determining the charge on a small sphere.

Figure 3



The sphere is suspended from a spring of spring constant $0.18\,\mathrm{N\,m^{-1}}$. It hangs between two parallel plates which can be connected to a high voltage supply.

(i) Explain why nylon thread is used for the suspension.

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(ii) Calculate the extension of the spring when a sphere of mass 1.5 g is suspended from it.
gravitational field strength = $9.8\,\mathrm{N\,kg^{-1}}$

(iii) Calculate the magnitude of the electric field strength between the plates when the 8000 V supply is switched on.

(iv) When the 8000 V supply is switched on, the sphere moves down a further 4.5 mm. Calculate the charge on the sphere.

(8 marks)

(c) One problem with this arrangement is the oscillations of the sphere that occur when the switch is closed.

(i) Show that the period of the oscillations produced is about 0.6 s.

(ii) In practice the oscillations are damped. Sketch a graph showing how the amplitude of the oscillations changes with time for the damped oscillation.

(5 marks)

18

Turn over for the next question

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2 The table shows data for some nuclei.

Element	***Z***	***A***	**Nuclear radius $R/10^{-15}$ m**	**Binding energy per nucleon/MeV**	**Emission (half-life)**
beryllium	4	9	2.5	6.46	stable
sodium	11	23	3.4	8.11	stable
manganese	25	56	4.6	8.74	β^-(2.6 h)

$$1\text{ eV} = 1.6 \times 10^{-19}\text{ J}$$

speed of electromagnetic radiation $= 3.0 \times 10^{8}\text{ m s}^{-1}$

(a) (i) Show that these data support the rule that

$$R = R_0 A^{\frac{1}{3}}$$

where R_0 is a constant.

(ii) The mass of a nucleon is about 1.7×10^{-27} kg. Calculate the density of nuclear matter.

(6 marks)

(b) (i) Explain what is meant by the binding energy of a nucleus.

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(ii) Show that the total binding energy of a sodium-23 nucleus is about 3×10^{-11} J.

(iii) Calculate the mass-equivalent of this binding energy.

(5 marks)

(c) Nuclear structure can be explored by bombarding the nuclei with alpha particles. The de Broglie wavelength of the alpha particle must be similar to the nuclear diameter. Calculate the energy of an alpha particle that could be used to explore the structure of manganese-56.

Planck constant = 6.6×10^{-34} J s
mass of an alpha particle = 6.8×10^{-27} kg

(4 marks)

(d) (i) State the proton number and nucleon number of the nucleus formed by the decay of manganese-56.

Proton number……………………… Nucleon number………………………

(ii) The activity of a sample of manganese-56 varies with time according to the equation

$$A = A_0 e^{-\lambda t}.$$

What value should be used for λ in calculations involving manganese-56 when t is in seconds?

(4 marks)

19

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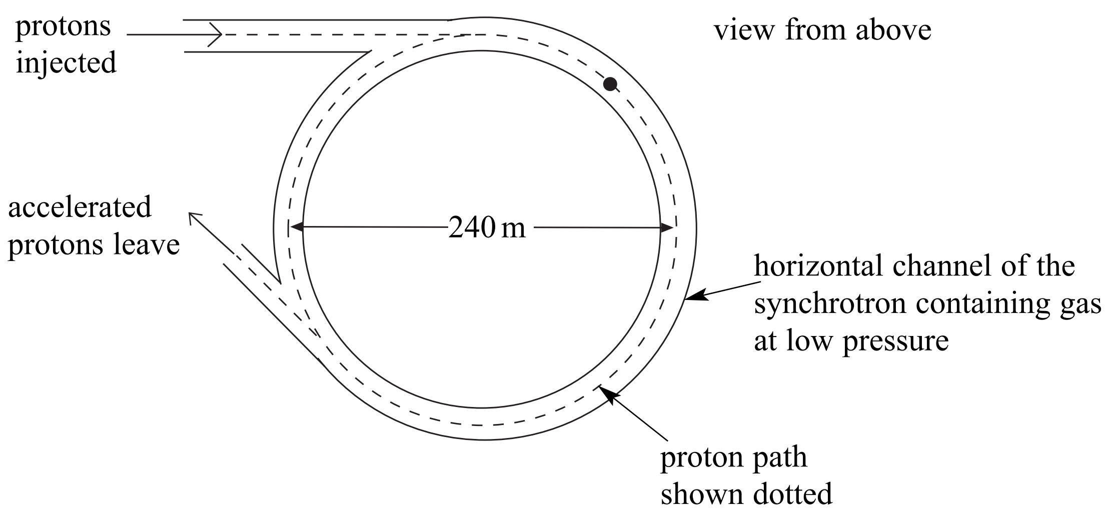
3 **Figure 4** shows the path of protons in a proton synchrotron.

Figure 4



The protons are injected at a speed of $1.2 \times 10^5\,\text{m s}^{-1}$ and a magnetic field is applied to make them move in a circular path.

(a) (i) Calculate the magnetic flux density of the field required for protons to move in the circular path when their speed is $1.2 \times 10^5\,\text{m s}^{-1}$.

mass of a proton $= 1.7 \times 10^{-27}$ kg

proton charge $= 1.6 \times 10^{-19}$ C

(ii) Explain how the magnetic flux density required to maintain the circular path has to change as the kinetic energy of the protons increases.

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(5 marks)

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(b) To reduce the energy lost by protons in collisions with gas atoms, the gas in the channel is at a very low pressure of 1.0×10^{-13} Pa.

Avogadro constant = $6.0 \times 10^{23}\ \text{mol}^{-1}$

universal gas constant = $8.3\ \text{J mol}^{-1}\ \text{K}^{-1}$

The temperature of the gas is 300 K.
Calculate the number of atoms of gas per cubic metre in the channel.

(4 marks)

(c) Discuss the ways in which protons can lose energy when colliding with gas atoms.

Two of the 6 marks are available for the quality of your written communication.

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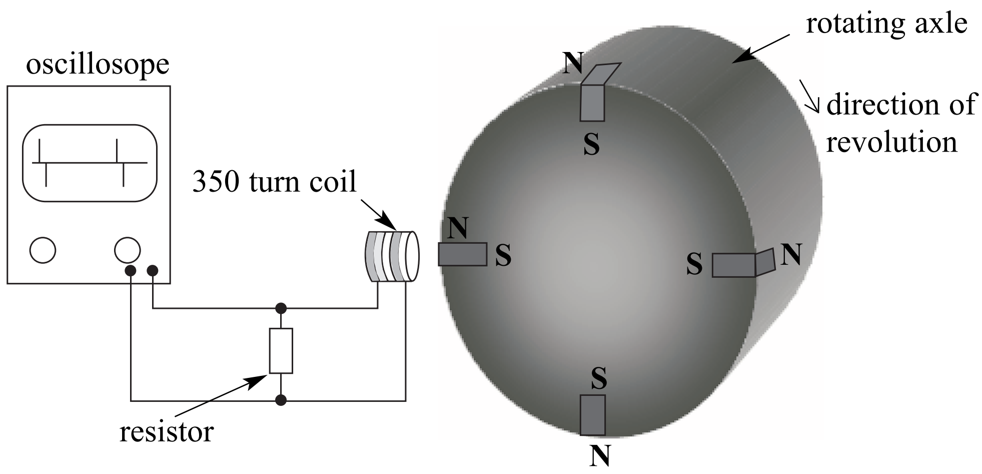
(6 marks)

15

4 **Figure 5** shows a system used by an engineer to determine the rate of revolution of a rotating axle.

Figure 5



Four small bar magnets are embedded in the axle as shown. The **N** pole of each magnet is towards the outside of the axle. A voltage is produced between the terminals of a coil placed close to the rotating axle. The voltage produced is monitored using an oscilloscope. The waveform produced is shown in **Figure 6**.

Figure 6

Oscilloscope grid marked in cm

The Y amplifier setting = $5\,\text{mV cm}^{-1}$

The time-base setting = $10\,\text{ms cm}^{-1}$

(a) Determine the number of revolutions made by the axle in one minute.

(3 marks)

(b) (i) Use Faraday's laws to explain how the voltage pulses are produced.

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(ii) The coil has 350 turns. Determine the maximum rate of change of flux through the coil.

(6 marks)

(c) Use Lenz's law to explain the production of positive and negative voltage pulses.

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(3 marks)

(d) Draw on **Figure 6** the waveform that shows the changes you would expect to see when the rate of revolution of the axle increases.

(3 marks)

15

Turn over

The passage for answering Questions 5 to 8 is printed on the loose insert, INSERT TO Jun07/PHB5. Read the passage before answering the questions.

5 (a) Calculate

(i) the speed of a GPS satellite in orbit,

(ii) the period of the orbit of a satellite used in the Global Positioning System.

(5 marks)

(b) Calculate the change in potential energy of the 1700 kg satellite when the satellite is launched from the surface of the Earth to its orbital height.

(3 marks)

(c) Explain why the total energy supplied by fuel to launch the satellite is greater than the change in potential energy of the satellite calculated in part (b).

Two of the 7 marks are available for the quality of your written communication.

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(7 marks)

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6 (a) (i) At point **P** in **Figure 7** the signal is received 0.06742 s after transmission. Calculate the distance between **P** and the satellite. Give your answer to 4 significant figures.

(ii) Use data from the article to find the height of **X** above the Earth's surface.

(iii) Estimate the distance between **P** and the point on the Earth's surface immediately below the satellite. The curvature of the Earth may be ignored in this question.

(4 marks)

(b) Explain why high precision in measuring the time is necessary to determine a position to within a metre.

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(2 marks)

6

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7 (a) **Figure 9** shows that the position can be fixed by the signals from three satellites. Explain why a signal from a fourth satellite is needed.

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(2 marks)

(b) Give **three** reasons mentioned in the article why, even with accurate atomic clocks in the satellite and receiver, the exact position of the receiver may still not be known.

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(*3 marks*)

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Turn over for the next question

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8 (a) (i) Suggest why a frequency in the UHF band has to be used for transmitting the signal.

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(ii) How does the photon energy for the UHF transmission compare with the photon energy from the radiation emitted from caesium-133 in the atomic clock?

(3 marks)

(b) Explain, with the aid of sketches, what is meant by a 'unique digital signal' (line 11).

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(2 marks)

(c) Explain why time measured using a caesium-133 atomic clock is more reliable than that measured using a quartz clock.

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(2 marks)

7

END OF QUESTIONS

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PHYSICS (SPECIFICATION B) **PHB5**
Unit 5 Fields and their Applications

ASSESSMENT and QUALIFICATIONS ALLIANCE

Read the following passage to help in answering Questions 5, 6, 7 and 8.

The Global Positioning System (GPS)

GPS is a worldwide radio-navigation system consisting of 24 satellites and their ground stations. Civilian systems can use these as reference points to calculate positions accurate to within a metre. In a sense it's like giving every square metre on the planet a unique address. More advanced forms can determine position to better than a centimetre!

The satellites have masses that vary from 450 kg to 1700 kg and are in orbits of radius 26 600 km. The orbits are arranged so that at any time at least 4 of the satellites (the minimum required for accurate positioning) are visible from any point on the Earth's surface.

A control centre communicates the position of every satellite to GPS receivers. This is known as 'almanac data'. If this data is inaccurate then there will be an error in the position recorded.

Each satellite transmits at the same frequency in the UHF band (1575.42 MHz) but each satellite has a unique digital signal. The signal from each satellite is transmitted at exactly the same instant as a similar signal is produced in the GPS receiver. The delay between its own signal and that received from the satellite is the time taken for the signal to travel from the satellite to the receiver so, knowing that the wave speed is $2.998 \times 10^8\ \text{m s}^{-1}$, the distance between the satellite and the receiver can be found. The signal from a satellite directly overhead takes about 0.06738 s to reach the receiver. The receiver calculates the distances for each satellite that is 'visible' and calculates the position of the receiver for use in the display.

Figure 7 shows the points on the circumference of a circle (centre **C**) on the Earth's surface that are possible positions of the receiver when the signal is received 0.06742 s after it was transmitted.

Figure 7

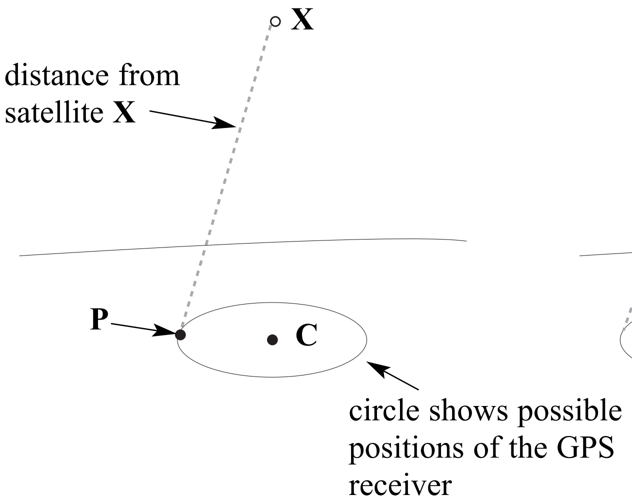
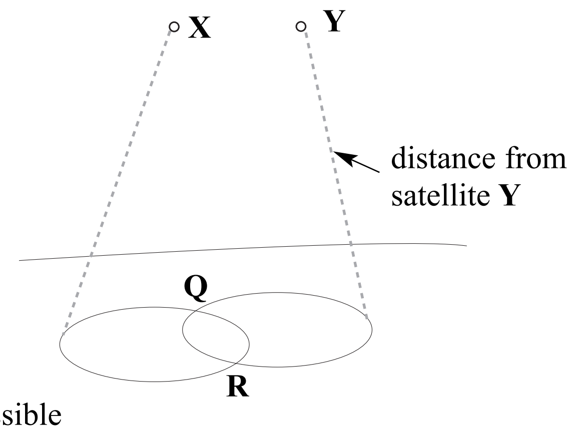


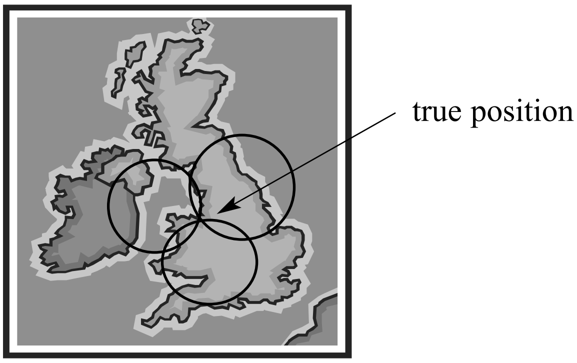
Figure 8



Using the time delay of the signal from a second satellite **Y** gives another set of possible positions. The actual position could be at either of the intersections **Q** and **R** shown in **Figure 8**. Using the distance from a third satellite defines whether **Q** or **R** is the true position, as shown in **Figure 9**.

Figure 9

Not to scale



There are a number of ways in which errors can occur. The reported position of a satellite may be inaccurate due to the attractions of astronomical objects that have not been accounted for; the waves travel slower in the ionosphere and signals may arrive at the receiver by different paths due to tall buildings or mountains. It is also vital that the digital signals from satellites and that produced internally by the receiver are synchronised. If the timing of the signal from a satellite is inaccurate by even 1 microsecond the error in the position could be hundreds of metres. To achieve this accuracy each satellite has its own atomic clock.

Atomic clocks

The basis of atomic clocks is the transition of electrons in atoms, a process that is not influenced by physical conditions. The transition between two specified levels in caesium-133 is used to define the second. One second is the time taken for 9 192 631 770 complete oscillations of the electromagnetic radiation from a caesium atom. Knowing the number of oscillations that have occurred, any time interval can be determined.

At present atomic clocks are physically large and expensive so GPS receivers use much cheaper quartz clocks. When put in a suitable electronic circuit, a quartz crystal vibrates and generates an alternating voltage of constant frequency that can be used to operate an electronic clock display.

The accuracy of a quartz clock depends on the crystal's size, shape and temperature. Since no two crystals are exactly alike, no two quartz clocks keep exactly the same time. However, a quartz clock can be continuously corrected using a signal from a fourth satellite. If the signal from the fourth satellite produces a position that is not consistent with that from the other three, the receiver clock is readjusted so that all four satellites produce a unique position. If a small atomic clock could be made then position could be found using fewer satellites.

The following data is needed to answer the questions

universal gravitational constant	$= 6.7 \times 10^{-11}$ N m^2 kg^{-2}
mass of the Earth	$= 6.0 \times 10^{24}$ kg
radius of the Earth	$= 6400$ km

GCE PHYSICS (SPECIFICATION B)
Formulae Sheets

Foundation Physics Mechanics Formulae

moment of force $= Fd$

$v = u + at$

$s = ut + \frac{1}{2}at^2$

$v^2 = u^2 + 2as$

$s = \frac{1}{2}(u + v)t$

for a spring, $F = k\Delta l$

energy stored in a spring $= \frac{1}{2}F\Delta l = \frac{1}{2}k(\Delta l)^2$

$T = \dfrac{1}{f}$

Foundation Physics Electricity Formulae

$I = nAvq$

terminal p.d. $= E - Ir$

in series circuit, $R = R_1 + R_2 + R_3 + ...$

in parallel circuit, $\dfrac{1}{R} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + ...$

output voltage across $R_1 = \left(\dfrac{R_1}{R_1 + R_2}\right) \times$ input voltage

Waves and Nuclear Physics Formulae

fringe spacing $= \dfrac{\lambda D}{d}$

single slit diffraction minimum $\sin\theta = \dfrac{\lambda}{b}$

diffraction grating $n\lambda = d\sin\theta$

Doppler shift $\dfrac{\Delta f}{f} = \dfrac{v}{c}$ for $v << c$

Hubble law $v = Hd$

radioactive decay $A = \lambda N$

Properties of Quarks

Type of quark	Charge	Baryon number
up u	$+\frac{2}{3}e$	$+\frac{1}{3}$
down d	$-\frac{1}{3}e$	$+\frac{1}{3}$
$\overline{\text{u}}$	$-\frac{2}{3}e$	$-\frac{1}{3}$
$\overline{\text{d}}$	$+\frac{1}{3}e$	$-\frac{1}{3}$

Lepton Numbers

Particle	Lepton number L		
	L_e	L_μ	L_τ
e^-	1		
e^+	–1		
ν_e	1		
$\overline{\nu}_e$	–1		
μ^-		1	
μ^+		–1	
ν_μ		1	
$\overline{\nu}_\mu$		–1	
τ^-			1
τ^+			–1
ν_τ			1
$\overline{\nu}_\tau$			–1

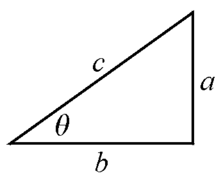
Geometrical and Trigonometrical Relationships

circumference of circle $= 2\pi r$

area of a circle $= \pi r^2$

surface area of sphere $= 4\pi r^2$

volume of sphere $= \frac{4}{3}\pi r^3$



$\sin\theta = \dfrac{a}{c}$

$\cos\theta = \dfrac{b}{c}$

$\tan\theta = \dfrac{a}{b}$

$c^2 = a^2 + b^2$

Foundation Physics Mechanics Formulae

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e^+	–1		
ν_e	1		
$\overline{\nu}_e$	–1		
μ^-		1	
μ^+		–1	
ν_μ		1	
$\overline{\nu}_\mu$		–1	
τ^-			1
τ^+			–1
ν_τ			1
$\overline{\nu}_\tau$			–1

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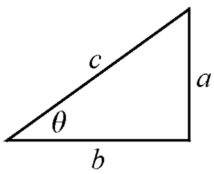

$\sin\theta = \dfrac{a}{c}$

$\cos\theta = \dfrac{b}{c}$

$\tan\theta = \dfrac{a}{b}$

$c^2 = a^2 + b^2$