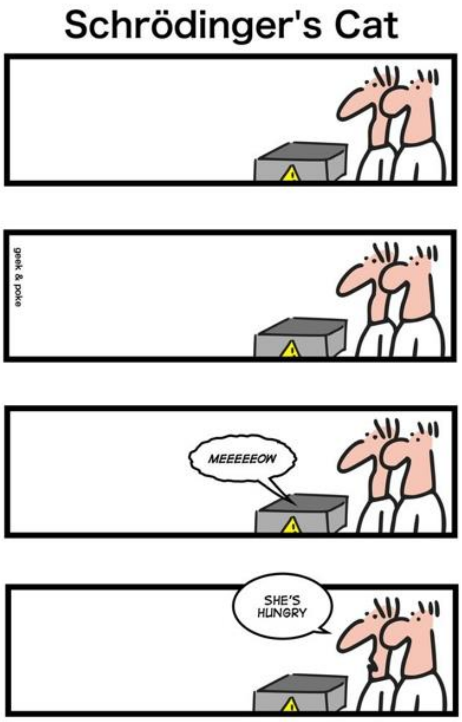
St Ninian’s High School

Advanced Higher Physics

Unit 2 Homework
Quanta



DATA SHEET

COMMON PHYSICAL QUANTITIES

Quantity	*Symbol*	*Value*	*Quantity*	*Symbol*	*Value*
Gravitational acceleration on Earth	g	$9{\cdot}8\ \text{m s}^{-2}$	Mass of electron	m_e	$9{\cdot}11 \times 10^{-31}$ kg
Radius of Earth	R_E	$6{\cdot}4 \times 10^{6}$ m	Charge on electron	e	$-1{\cdot}60 \times 10^{-19}$ C
Mass of Earth	M_E	$6{\cdot}0 \times 10^{24}$ kg	Mass of neutron	m_n	$1{\cdot}675 \times 10^{-27}$ kg
Mass of Moon	M_M	$7{\cdot}3 \times 10^{22}$ kg	Mass of proton	m_p	$1{\cdot}673 \times 10^{-27}$ kg
Radius of Moon	R_M	$1{\cdot}7 \times 10^{6}$ m	Mass of alpha particle	m_α	$6{\cdot}645 \times 10^{-27}$ kg
Mean Radius of Moon Orbit		$3{\cdot}84 \times 10^{8}$ m	Charge on alpha particle		$3{\cdot}20 \times 10^{-19}$ C
Solar radius		$6{\cdot}955 \times 10^{8}$ m	Planck's constant	h	$6{\cdot}63 \times 10^{-34}$ J s
Mass of Sun		$2{\cdot}0 \times 10^{30}$ kg	Permittivity of free space	ε_0	$8{\cdot}85 \times 10^{-12}\ \text{F m}^{-1}$
1 AU		$1{\cdot}5 \times 10^{11}$ m	Permeability of free space	μ_0	$4\pi \times 10^{-7}\ \text{H m}^{-1}$
Stefan-Boltzmann constant	σ	$5{\cdot}67 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4}$	Speed of light in vacuum	c	$3{\cdot}0 \times 10^{8}\ \text{m s}^{-1}$
Universal constant of gravitation	G	$6{\cdot}67 \times 10^{-11}\ \text{m}^3\ \text{kg}^{-1}\ \text{s}^{-2}$	Speed of sound in air	v	$3{\cdot}4 \times 10^{2}\ \text{m s}^{-1}$

REFRACTIVE INDICES

The refractive indices refer to sodium light of wavelength 589 nm and to substances at a temperature of 273 K.

Substance	*Refractive index*	*Substance*	*Refractive index*
Diamond	2·42	Glycerol	1·47
Glass	1·51	Water	1·33
Ice	1·31	Air	1·00
Perspex	1·49	Magnesium Fluoride	1·38

SPECTRAL LINES

Element	*Wavelength/nm*	*Colour*
Hydrogen	656	Red
	486	Blue-green
	434	Blue-violet
	410	Violet
	397	Ultraviolet
	389	Ultraviolet
Sodium	589	Yellow

Element	*Wavelength/nm*	*Colour*
Cadmium	644	Red
	509	Green
	480	Blue

Lasers

Element	*Wavelength/nm*	*Colour*
Carbon dioxide	9550 10590	Infrared
Helium-neon	633	Red

PROPERTIES OF SELECTED MATERIALS

Substance	*Density/* kg m^{-3}	*Melting Point/* K	*Boiling Point/*K	*Specific Heat Capacity/* J kg^{-1} K^{-1}	*Specific Latent Heat of Fusion/* J kg^{-1}	*Specific Latent Heat of Vaporisation/* J kg^{-1}
Aluminium	$2{\cdot}70 \times 10^{3}$	933	2623	$9{\cdot}02 \times 10^{2}$	$3{\cdot}95 \times 10^{5}$	....
Copper	$8{\cdot}96 \times 10^{3}$	1357	2853	$3{\cdot}86 \times 10^{2}$	$2{\cdot}05 \times 10^{5}$	....
Glass	$2{\cdot}60 \times 10^{3}$	1400	....	$6{\cdot}70 \times 10^{2}$	....	....
Ice	$9{\cdot}20 \times 10^{2}$	273	....	$2{\cdot}10 \times 10^{3}$	$3{\cdot}34 \times 10^{5}$	....
Glycerol	$1{\cdot}26 \times 10^{3}$	291	563	$2{\cdot}43 \times 10^{3}$	$1{\cdot}81 \times 10^{5}$	$8{\cdot}30 \times 10^{5}$
Methanol	$7{\cdot}91 \times 10^{2}$	175	338	$2{\cdot}52 \times 10^{3}$	$9{\cdot}9 \times 10^{4}$	$1{\cdot}12 \times 10^{6}$
Sea Water	$1{\cdot}02 \times 10^{3}$	264	377	$3{\cdot}93 \times 10^{3}$	....	....
Water	$1{\cdot}00 \times 10^{3}$	273	373	$4{\cdot}19 \times 10^{3}$	$3{\cdot}34 \times 10^{5}$	$2{\cdot}26 \times 10^{6}$
Air	1·29	....	....	....	....	....
Hydrogen	$9{\cdot}0 \times 10^{-2}$	14	20	$1{\cdot}43 \times 10^{4}$	....	$4{\cdot}50 \times 10^{5}$
Nitrogen	1·25	63	77	$1{\cdot}04 \times 10^{3}$	....	$2{\cdot}00 \times 10^{5}$
Oxygen	1·43	55	90	$9{\cdot}18 \times 10^{2}$	....	$2{\cdot}40 \times 10^{4}$

The gas densities refer to a temperature of 273 K and a pressure of $1{\cdot}01 \times 10^{5}$ Pa.

2.1 Introduction to Quantum Theory

1.

(a) Explain qualitatively how the Bohr Model of the atom can account for line emission spectra. 2

(b) It is possible to calculate a de Broglie wavelength for a moving object.

A ball of mass 45 g has a speed of 68 m s^{-1}.

(i) Calculate the de Broglie wavelength for the ball. 3

(ii) Explain why wave-like properties are not observed for the ball. 1

(6)

2.

(a) State what is meant by the Uncertainty Principle in relation to the position and momentum of a subatomic particle. 1

(b) An athlete has a mass of 70 kg. At the finish line the position of the athlete has an uncertainty of $1{\cdot}0 \times 10^{-3}$ m.

Calculate the minimum uncertainty in the momentum of the athlete at the finish line. 3

(c) It takes about $1{\cdot}6 \times 10^{-13}$ J of energy to create an electron-positron pair.

For what approximate period of time can this amount of energy be borrowed before it has to be paid back by electron-positron annihilation? 3

(7)

3.

(*a*) Bohr's model of the hydrogen atom includes assumptions about the orbiting electron. One of these is that the electron moves in a circular orbit centred on the nucleus.

(i) State briefly one of the other assumptions. 1

(ii) By considering the electron as a point mass m travelling around the nucleus, show that the radii of the allowed orbits r_n are given by

$$r_n = \frac{nh}{2\pi mv}$$

where the remaining symbols have their usual meanings. 2

(iii) Calculate the speed of an electron in the first allowed orbit of radius $5{\cdot}3 \times 10^{-11}$ m. 2

(*b*) Planck and Einstein suggested that electromagnetic radiation exhibits a wave-particle duality. De Broglie extended this idea to matter.

(i) Write down an expression for the wavelength λ associated with a particle that has a momentum of magnitude p. 1

(ii) (A) A woman of mass 50 kg walks through a doorway at a speed of $1{\cdot}5\ \mathrm{m\,s^{-1}}$. Calculate her de Broglie wavelength. 3

(B) Explain why the effect of diffraction is negligible when the woman passes through the doorway. 1

(10)

4.

(*a*) (i) Electrons exhibit wave-like behaviour.

Give **one** example of experimental evidence which supports this statement. 1

(ii) Electrons can also exhibit particle-like behaviour.

Give **one** example of experimental evidence which supports this statement. 1

(*b*) De Broglie showed that it is possible to calculate a wavelength for a moving object.

A tennis ball of mass 60 g is served at $55\ \mathrm{m\,s^{-1}}$.

(i) Calculate the de Broglie wavelength for this ball. 3

(ii) Explain why wave-like properties are not observed for this ball. 1

(6)

5.

(*a*) Electrons can exhibit wave-like behaviour. Give **one** example of evidence which supports this statement. **1**

(*b*) The Bohr model of the hydrogen atom suggests a nucleus with an electron occupying one of a series of stable orbits.

A nucleus and the first two stable orbits are shown in Figure 6.

(6)

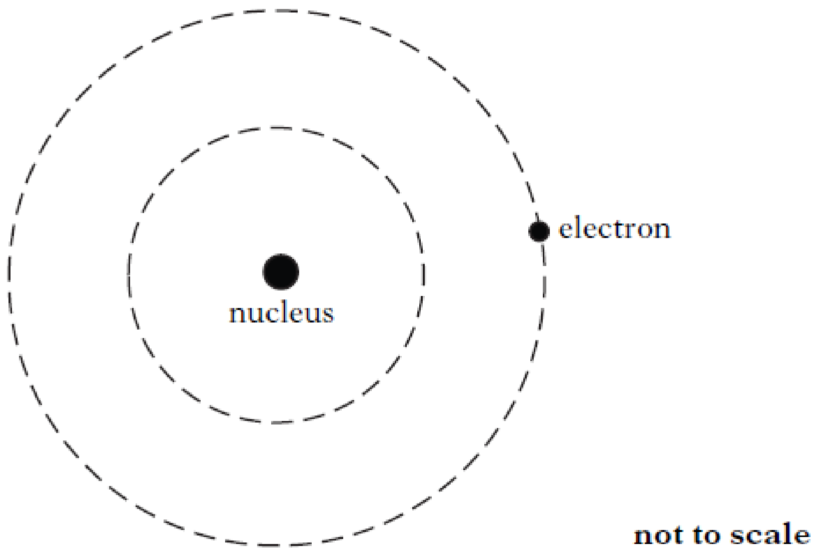


Figure 6

(i) Calculate the angular momentum of the electron in the second stable orbit. 3

(ii) Starting with the relationship

$$mrv = \frac{nh}{2\pi}$$

show that the circumference of the second stable orbit is equal to two electron wavelengths. 3

(iii) The circumference of the second stable orbit is $1{\cdot}3 \times 10^{-9}$ m.

Calculate the speed of the electron in this orbit. **2**

(8)

6.

The Bohr model of the atom suggests that the angular momentum of an electron orbiting a nucleus is quantised.

A hydrogen atom consists of a single electron orbiting a single proton. Figure 10A shows some of the possible orbits for the electron in a hydrogen atom.

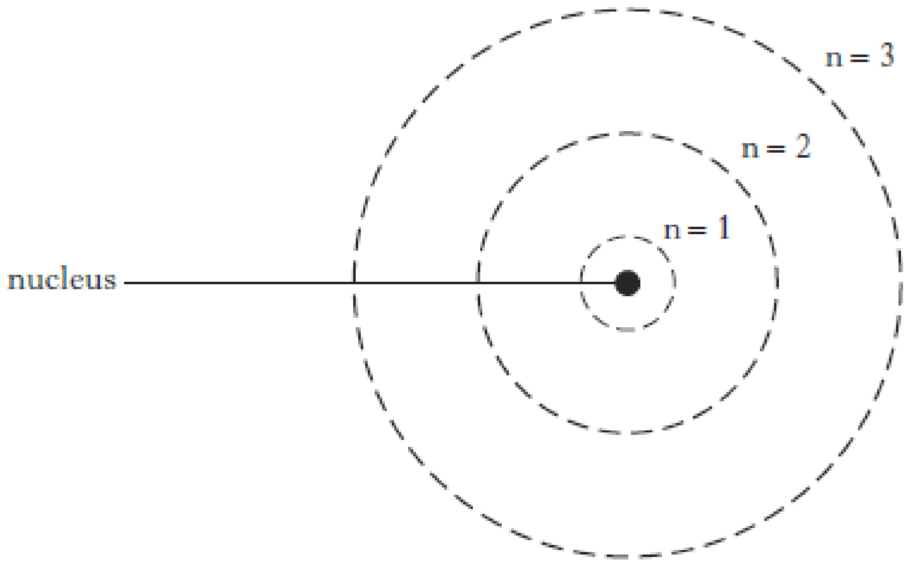


Figure 10A

The table shows the values of the radii for the first three orbits.

Orbit number, n	*Orbital radius*/10^{-10} m
1	0·53
2	2·1
3	4·8

(*a*) Calculate the speed of the electron in the orbit number 3. 3

(*b*) Calculate the de Broglie wavelength associated with this electron. 3

(*c*) Some of the limitations of the Bohr model of the atom are addressed by Quantum Mechanics.

(i) The position of an electron in a hydrogen atom was measured with an uncertainty of 0·15 nm.

Calculate the minimum uncertainty in its momentum. 3

6.

(c) (continued)

(ii) A diagram of electron probability distribution for the hydrogen atom is shown in Figure 10B.

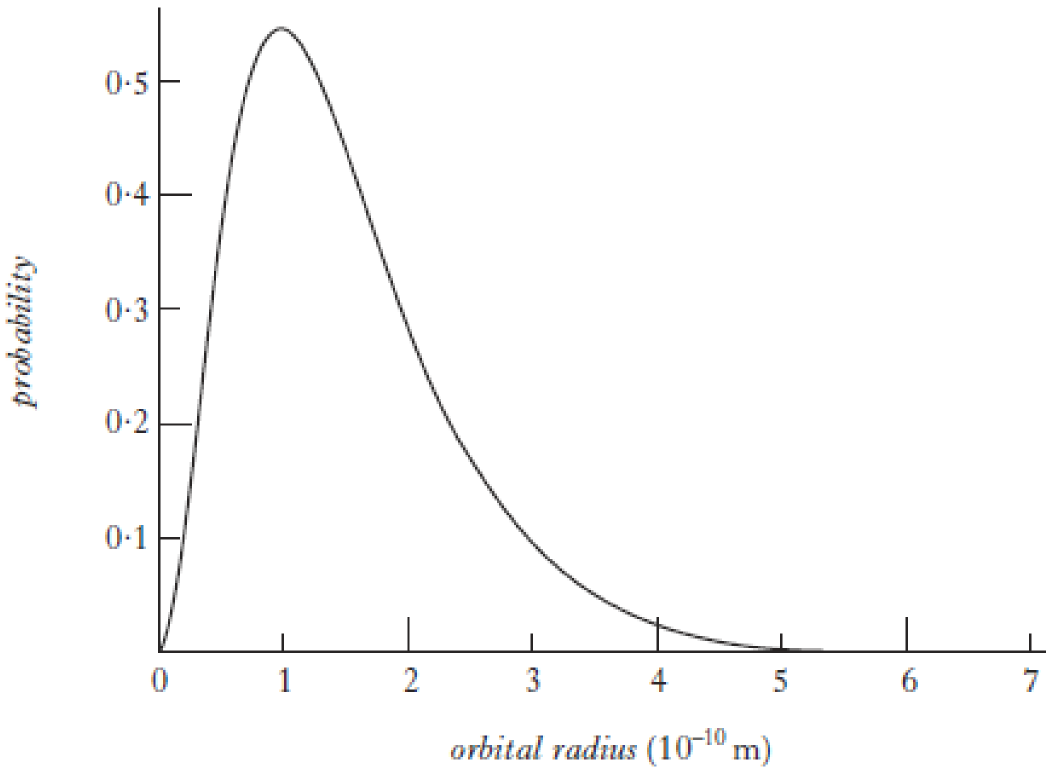


Figure 10B

Comment on the position of the electron in this orbital. **2**

(11)

7.

One of the key ideas in Quantum Theory is the Heisenberg Uncertainty Principle.

(*a*) The uncertainty in the position of a particle can be estimated as its de Broglie wavelength. An electron has an average speed of $3{\cdot}2 \times 10^6$ m s^{-1}.

(i) Calculate the minimum uncertainty in the momentum of this electron. 4

(ii) It is not possible to measure accurately the position of an electron using visible light. Describe the effect of using a beam of X-rays rather than visible light on the measurement of the electron's position and momentum. Justify your answer. **2**

(*b*) Polonium 212 decays by alpha emission. The energy required for an alpha particle to escape from the Polonium nucleus is 26 MeV. Prior to emission, alpha particles in the nucleus have an energy of 8·78 MeV. With reference to the Uncertainty Principle, explain how this process can occur. **2**

(8)

8.

In 1928 Davisson and Germer fired a beam of electrons through a very thin layer of nickel in a vacuum, which resulted in the production of a diffraction pattern.

(*a*) (i) What did they conclude from the results of their experiment? **1**

(ii) Give **one** example of experimental evidence that photons of light exhibit particle properties. **1**

(*b*) Calculate the de Broglie wavelength of an electron travelling at $4{\cdot}4 \times 10^6$ m s^{-1}. 3

(*c*) A 20 g bullet travelling at 300 m s^{-1} passes through a 500 mm gap in a target.

Using the data given, explain why no diffraction pattern is observed. 3

(*d*) (i) Describe the Bohr model of the hydrogen atom. **2**

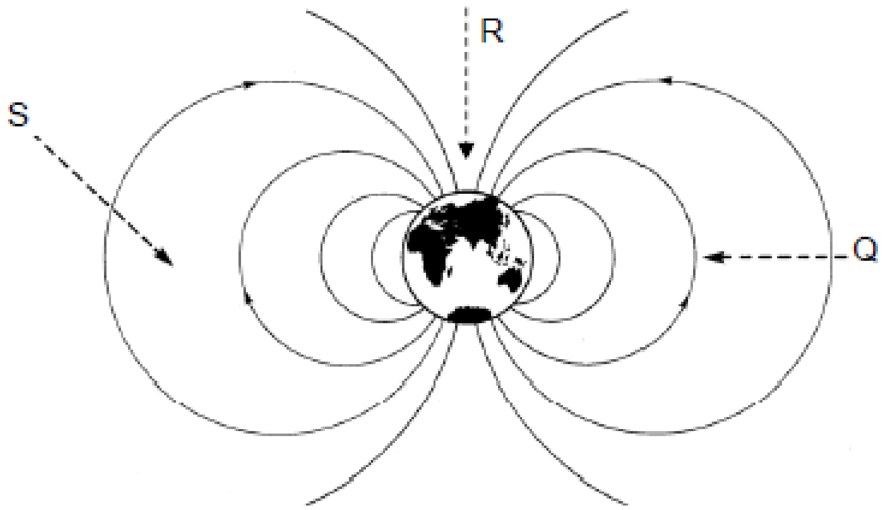
(ii) Calculate the angular momentum of an electron in the third stable orbit of a hydrogen atom. 3

(13)

2.2 Particles from Space

1.

The diagram shows the magnetic field lines in the region surrounding the Earth.



(a) Three positively charged particles initially approach the Earth along the paths Q, R and S.

(i) Describe the subsequent path of particle R. 1

(ii) Describe the subsequent path of particle S. 1

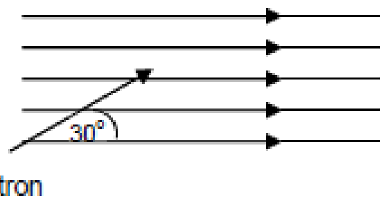
(b) A **proton** with a speed of $2{\cdot}0 \times 10^6$ m s^{-1} approaches the Earth along path Q at a point where the magnetic induction is 13×10^{-6} T.

Calculate the radius of curvature, in metres, of the path at a point where the magnetic induction is $1{\cdot}3 \times 10^{-5}$ T. 3

(5)

2.

(a) An electron travels at a speed of $1 \cdot 0 \times 10^7$ m s^{-1} as it enters a uniform field of magnetic induction 5·0 mT. The electron travels at an angle of 30° to the field.



Show that the radius of the resultant helical path of the electron is $5 \cdot 7 \times 10^{-3}$ m. 3

(b) Explain why the electron follows a helical path. 3

(6)

3.

The Sun is constantly losing mass through nuclear fusion. Particles also escape from the corona as shown in Figure 7A. This stream of particles radiating from the Sun is known as the Solar wind and its main constituent, by mass, is protons.

Figure 7A

(*a*) Astronomers estimate that the Sun loses mass at a rate of $1{\cdot}0 \times 10^9\,\text{kg s}^{-1}$. This rate has been approximately constant through the Sun's lifetime of $4{\cdot}6 \times 10^9$ years.

Estimate the mass lost by the Sun in its lifetime as a percentage of its current mass. **4**

(*b*) A proton in the solar wind has energy of 3·6 MeV.

(i) Calculate the velocity of this proton. **3**

(ii) The proton enters the magnetic field around the Earth at an angle of 50° as shown in Figure 7B. The magnetic field strength is 58 μT.

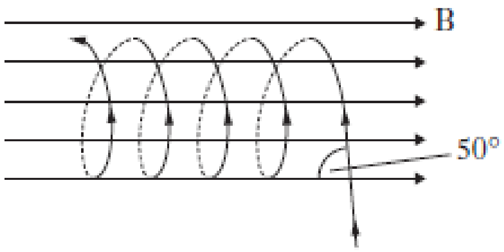


Figure 7B

(A) Explain the shape of the path followed by the proton in the magnetic field. **2**

(B) Calculate the radius of curvature of this path. **4**

(iii) An antiproton of energy 3·6 MeV enters the same region of the Earth's magnetic field at an angle of 30° to the field.

Describe **two** differences in the paths taken by the antiproton and the original proton. **2**

(15)