

# Quanta Problems

# Data

## Common Physical Quantities

| QUANTITY                          | SYMBOL         | VALUE  |
|-----------------------------------|----------------|--|
| Gravitational acceleration        | g              | 9.8 m s <sup>-2</sup>  |
| Radius of Earth                   | R <sub>E</sub> | 6.4 x 10 <sup>6</sup> m  |
| Mass of Earth                     | M <sub>E</sub> | 6.0 x 10 <sup>24</sup> kg  |
| Mass of Moon                      | M <sub>M</sub> | 7.3 x 10 <sup>22</sup> kg  |
| Mean radius of Moon orbit         |                | 3.84 x 10 <sup>8</sup> m   |
| Universal constant of gravitation | G              | 6.67 x 10 <sup>-11</sup> m <sup>3</sup> kg <sup>-1</sup> s <sup>-2</sup> |
| Speed of light in vacuum          | c              | 3.0 x 10 <sup>8</sup> m s <sup>-1</sup>                                  |
| Speed of sound in air             | v              | 3.4 x 10 <sup>2</sup> m s <sup>-1</sup>                                  |
| Mass of electron                  | m <sub>e</sub> | 9.11 x 10 <sup>-31</sup> kg  |
| Charge on electron                | e              | -1.60 x 10 <sup>-19</sup> C  |
| Mass of neutron                   | m <sub>n</sub> | 1.675 x 10 <sup>-27</sup> kg   |
| Mass of proton                    | m <sub>p</sub> | 1.673 x 10 <sup>-27</sup> kg   |
| Planck's constant                 | h              | 6.63 x 10 <sup>-34</sup> J s   |
| Permittivity of free space        | ε <sub>0</sub> | 8.85 x 10 <sup>-12</sup> F m <sup>-1</sup>                               |
| Permeability of free space        | μ <sub>0</sub> | 4π x 10 <sup>-7</sup> H m <sup>-1</sup>                                  |

## Astronomical Data

| Planet or satellite | Mass/ kg               | Density/ kg m <sup>-3</sup> | Radius/ m              | Grav. accel./ m s <sup>-2</sup> | Escape velocity/ m s <sup>-1</sup> | Mean dist from Sun/ m  | Mean dist from Earth/ m |
|---------------------|------------------------|-----------------------------|------------------------|---------------------------------|------------------------------------|------------------------|-------------------------|
| Sun                 | 1.99x 10 <sup>30</sup> | 1.41 x 10 <sup>3</sup>      | 7.0 x 10 <sup>8</sup>  | 274                             | 6.2 x 10 <sup>5</sup>              | --                     | 1.5 x 10 <sup>11</sup>  |
| Earth               | 6.0 x 10 <sup>24</sup> | 5.5 x 10 <sup>3</sup>       | 6.4 x 10 <sup>6</sup>  | 9.8                             | 11.3 x 10 <sup>3</sup>             | 1.5 x 10 <sup>11</sup> | --                      |
| Moon                | 7.3 x 10 <sup>22</sup> | 3.3 x 10 <sup>3</sup>       | 1.7 x 10 <sup>6</sup>  | 1.6                             | 2.4 x 10 <sup>3</sup>              | --                     | 3.84 x 10 <sup>8</sup>  |
| Mars                | 6.4 x 10 <sup>23</sup> | 3.9 x 10 <sup>3</sup>       | 3.4 x 10 <sup>6</sup>  | 3.7                             | 5.0 x 10 <sup>3</sup>              | 2.3 x 10 <sup>11</sup> | --                      |
| Venus               | 4.9 x 10 <sup>24</sup> | 5.3 x 10 <sup>3</sup>       | 6.05 x 10 <sup>6</sup> | 8.9                             | 10.4 x 10 <sup>3</sup>             | 1.1 x 10 <sup>11</sup> | --                      |

## Tutorial 1.0

### Quantum theory

1. The uncertainty in an electron's position relative to an axis is given as  $\pm 5.0 \times 10^{-12}$  m. Calculate the least uncertainty in the simultaneous measurement of the electron's momentum relative to the same axis.
2. An electron moves along the  $x$ -axis with a speed of  $2.05 \times 10^6$  m s $^{-1} \pm 0.50\%$ . Calculate the minimum uncertainty with which you can simultaneously measure the position of the electron along the  $x$ -axis.
3. An electron spends approximately 1.0 ns in an excited state. Calculate the uncertainty in the energy of the electron in this excited state.
4. The position of an electron can be predicted to within  $\pm 40$  atomic diameters. The diameter of an atom can be taken as  $1.0 \times 10^{-10}$  m. Calculate the simultaneous uncertainty in the electron's momentum.
5. Calculate the de Broglie wavelength of:
  - (a) an electron travelling at  $4.0 \times 10^6$  m s $^{-1}$
  - (b) a proton travelling at  $6.5 \times 10^6$  m s $^{-1}$
  - (c) a car of mass 1000 kg travelling at 120 km per hour.
6. An electron and a proton both move with the same velocity of  $3.0 \times 10^6$  m s $^{-1}$ . Which has the larger de Broglie wavelength and by how many times larger (to 2 significant figures)?
7. Gamma rays have an energy of  $4.2 \times 10^{-13}$  J.
  - (a) Calculate the wavelength of the gamma rays.
  - (b) Calculate the momentum of the gamma rays.
8. An electron is accelerated from rest through a p.d. of 200 V in a vacuum.
  - (a) Calculate the final speed of the electron.
  - (b) Calculate the de Broglie wavelength of the electron at this speed.
  - (c) Would this electron show particle or wave-like behaviour when passing through an aperture of diameter 1 mm?
9. An electron is accelerated from rest through a p.d. of 2.5 kV. Calculate the final de Broglie wavelength of this electron.
10. An electron microscope accelerates electrons until they have a wavelength of 40 pm ( $40 \times 10^{-12}$  m). Calculate the p.d. in the microscope required to do this assuming the electrons start from rest.
11. Relativistic effects on moving objects can be ignored provided the velocity is less than 10% of the speed of light. What is the minimum wavelength of an electron produced by an electron microscope where relativistic effects can be ignored?

12. An electron moves round the nucleus of a hydrogen atom.

(a) Calculate the angular momentum of this electron:

- (i) in the first stable orbit
- (ii) in the third stable orbit.

(b) Starting with the relationship

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

show that the circumference of the third stable orbit is equal to three electron wavelengths.

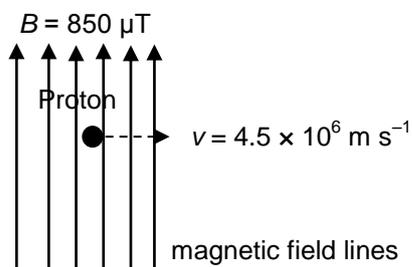
(c) The speed of an electron in the second stable orbit is  $1.1 \times 10^6 \text{ m s}^{-1}$ .

- (i) Calculate the wavelength of the electron.
- (ii) Calculate the circumference of the second stable orbit.

## Tutorial 2.0

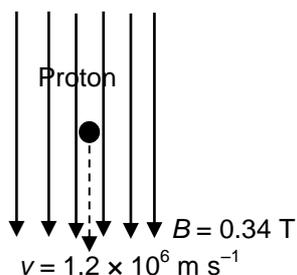
### Particles from space

1. An electron moves with a speed of  $4.8 \times 10^6 \text{ m s}^{-1}$  at right angles to a uniform magnetic field of magnetic induction 650 mT.  
Calculate the magnitude of the force acting on the electron.
2. A proton moves with a speed of  $3.0 \times 10^4 \text{ m s}^{-1}$  at right angles to a uniform magnetic field. The magnetic induction is 0.8 T. The charge on the proton is  $+1e$ .  
Calculate the magnitude of the force acting on the proton.
3. A neutron moves at right angles to a uniform magnetic field.  
Explain why the neutron's motion is unaffected by the magnetic field.
4. (a) A proton moves through a uniform magnetic field as shown in the diagram.



Calculate the magnetic force exerted on the proton.

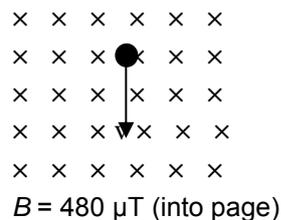
- (b) Another proton moves through this uniform magnetic field.



What is the magnetic force exerted on the proton? Explain your answer.

5. An electron experiences a force of  $2.5 \times 10^{-13} \text{ N}$  as it moves at right angles to a uniform magnetic field of magnetic induction 350 mT.  
Calculate the speed of the electron.
6. A muon experiences a force of  $1.5 \times 10^{-16} \text{ N}$  when travelling at a speed of  $2.0 \times 10^7 \text{ m s}^{-1}$  at right angles to a magnetic field. The magnetic induction of this field is  $4.7 \times 10^{-5} \text{ T}$ .  
What is the magnitude of the charge on the muon?

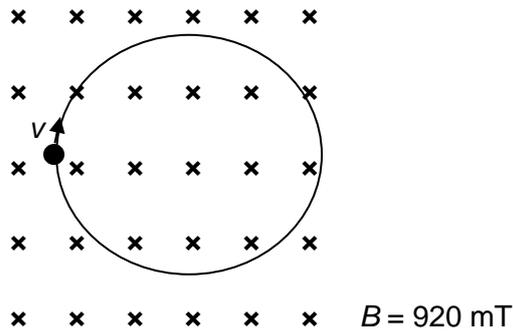
7. An alpha particle is a helium nucleus containing two protons and two neutrons. The alpha particle experiences a force of  $1.4 \times 10^{-12}$  N when moving at  $4.8 \times 10^5$  m s<sup>-1</sup> at right angles to a uniform magnetic field.  
Calculate the magnitude of the magnetic induction of this field.
8. An electron moves at right angles to a uniform magnetic field of magnetic induction 0.16 T. The speed of the electron is  $8.2 \times 10^6$  m s<sup>-1</sup>.
- Calculate the force exerted on the electron.
  - Explain why the electron moves in a circle.
  - Calculate the radius of this circle.
9. A proton moves through the same magnetic field as in question 8 with the same speed as the electron ( $8.2 \times 10^6$  m s<sup>-1</sup>).  
Calculate the radius of the circular orbit of the proton.
10. An electron moves with a speed of  $3.8 \times 10^6$  m s<sup>-1</sup> perpendicular to a uniform magnetic field.



Calculate:

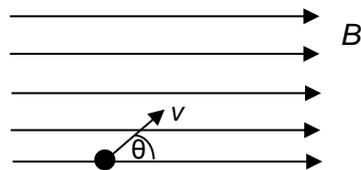
- the radius of the circular orbit taken by the electron
  - the central force acting on the electron.
11. An alpha particle travels in a circular orbit of radius 0.45 m while moving through a magnetic field of magnetic induction 1.2 T. The mass of the alpha particle is  $6.645 \times 10^{-27}$  kg. Calculate:
- the speed of the alpha particle in the orbit
  - the orbital period of the alpha particle
  - the kinetic energy of the alpha particle in this orbit.

12. A proton moves in a circular orbit of radius 22 mm in a uniform magnetic field as shown in the diagram.



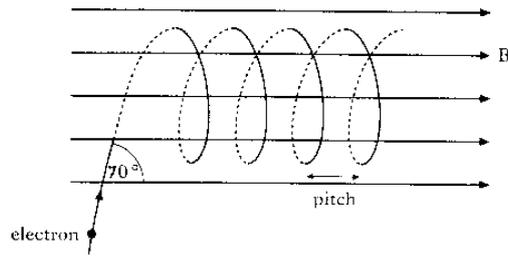
Calculate the speed of the proton.

13. An electron moves with a speed of  $5.9 \times 10^5 \text{ m s}^{-1}$  in a circular orbit of radius  $5.5 \mu\text{m}$  in a uniform magnetic field.  
Calculate the magnetic induction of the magnetic field.
14. A sub-atomic particle moves with a speed of  $2.09 \times 10^6 \text{ m s}^{-1}$  in a circular orbit of radius 27 mm in a uniform magnetic field. The magnetic induction is 0.81 T.  
Calculate the charge to mass ratio of the sub-atomic particle and suggest a name for the particle. Give a reason for your answer.
15. A charged particle enters a uniform magnetic field with a velocity  $v$  at an angle  $\theta$  as shown.



- Write down an expression for the horizontal component of velocity.
- Write down an expression for the vertical component of velocity.
- Which of these components will stay unchanged as the charged particle continues its journey? Give a reason for your answer.

16. An electron travelling at a constant speed of  $6.8 \times 10^6 \text{ m s}^{-1}$  enters a uniform magnetic field at an angle of  $70^\circ$  as shown and subsequently follows a helical path.



The magnetic induction is 230 mT.

Calculate:

- the component of the electron's initial velocity parallel to B;
  - the component of the electron's initial velocity perpendicular to B;
  - the central force acting on the electron;
  - the radius of the helix;
  - the period of electron rotation in the helix;
  - the pitch of the helix.
17. A proton travelling at  $5.8 \times 10^5 \text{ m s}^{-1}$  enters a uniform magnetic field at an angle of  $40^\circ$  to the horizontal (similar to the diagram in question 16). The proton subsequently follows a helical path.

The magnetic induction is 0.47 T.

Calculate:

- the component of the proton's initial velocity parallel to B;
  - the component of the proton's initial velocity perpendicular to B;
  - the central force acting on the proton;
  - the radius of the helix;
  - the period of proton rotation in the helix;
  - the pitch of the helix.
18. An electron travelling at  $1.3 \times 10^7 \text{ m s}^{-1}$  enters a uniform magnetic field at an angle of  $55^\circ$  and follows a helical path similar to that shown in question 16. The magnetic induction is 490 mT.

Calculate:

- the radius of the helix
  - the pitch of the helix.
19. Explain why most charged particles from the Sun enter the Earth's atmosphere near the north and south poles.
20. Explain what causes the Aurora Borealis to occur.