Lockerbie Academy Physics Department

2016

PARTICLES & WAVES ANSWERS

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Lockerbie Academy

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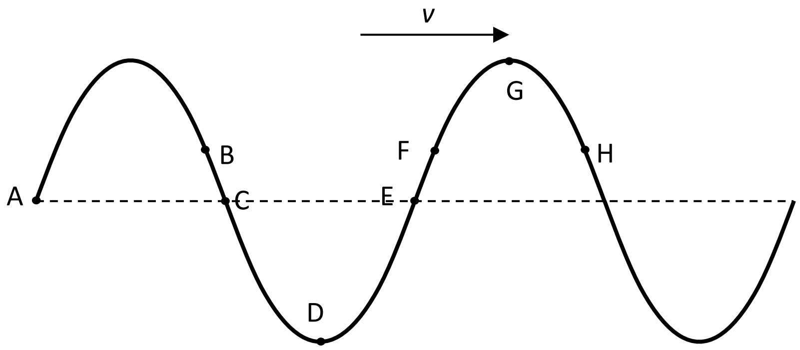
CHAPTER 2 PARTICLES & WAVES BACKGROUND

Revision

TUTORIAL 1: PHASE AND COHERENCE



Points ___ & ___ or ___ & ___ are in phase.

Points ___ & ___ or ___ & ___ or ___ & ___ are exactly out of phase.

Points ___ & ___ or ___ & ___ or ___ & ___ are 90° out of phase.

Points ___ and ___ are at present stationary.

Points ___, ___ and ___ are at present rising.

Points ___, ___ and ___ are at present dropping.

TUTORIAL 1: ANSWERS

PHASE AND COHERENCE

Points A & E, B & H are in phase

Points A& C, D & G, C&E are exactly out of phase

Points A& G, C & D, D & E, E & G are 90° out of phase

Points D & G are at present stationary

Points A, E and F are at present rising

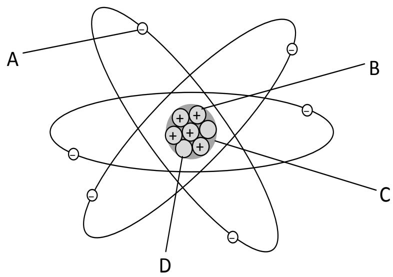
Points B, C, & H are at present dropping

CHAPTER 3: THE STANDARD MODEL

Symbol	Name	Protons	Neutrons	Electrons	Is there an isotope of the element in this table?
${}^{1}_{1}H$	Hydrogen	1	0	1	No
${}^{14}_{6}C$	Carbon	6	8	6	Yes
${}^{12}_{6}C$	Carbon	6	6	6	Yes
${}^{197}_{79}Au$	Gold	79	118	79	No
${}^{235}_{92}U$	Uranium	92	143	92	Yes
${}^{238}_{92}U$	Uranium	92	146	92	Yes
${}^{220}_{88}Ra$	Radium	88	132	88	No
${}^{222}_{86}Rn$	Radon	86	136	86	No

THE STANDARD MODEL /TUTORIALS

TUTORIAL 1: ORDERS OF MAGNITUDE



1. The diagram shows a simple model of the atom.
Match each of the letters A, B, C and D with the correct word from the list below.

electron ***neutron*** ***nucleus*** ***proton***

2. In the following table the numbers or words represented by the letters A, B, C, D, E, F and G are missing.

Order of magnitude/m	*Object*
10^{-15}	A
10^{-14}	B
10^{-10}	Diameter of hydrogen atom
10^{-4}	C
10^{0}	D
10^{3}	E
10^{7}	Diameter of Earth
10^{9}	F
10^{13}	Diameter of solar system
10^{21}	G

Match each letter with the correct words from the list below.

diameter of nucleus *diameter of proton* *diameter of Sun*
distance to nearest galaxy *height of Ben Nevis*
size of dust particle *your height*

TUTORIAL 1: ANSWERS - STANDARD MODEL

ORDERS OF MAGNITUDE

1. A= electron; B = proton; C = nucleus; D = neutron

2.

Order of magnitude/m	*Object*
10^{-15}	A = diameter of proton
10^{-14}	B = diameter of nucleus
10^{-10}	Diameter of hydrogen atom
10^{-4}	C = size of dust particle
10^{0}	D = your height
10^{3}	E = height of Ben Nevis
10^{7}	Diameter of Earth
10^{9}	F = diameter of Sun
10^{13}	Diameter of solar system
10^{21}	G = distance to nearest galaxy

TUTORIAL 2 FUNDAMENTAL PARTICLES AND INTERACTIONS

1. Name the particles represented by the following symbols.

(a) p (b) $\overline{p}$ (c) e (d) $\overline{e}$

(e) n (f) $\overline{n}$ (g) v (h) $\overline{v}$

2. A particle can be represented by a symbol $^{M}_{A}\mathrm{X}$ where M represents the mass number, A the atomic number and X identifies the type of particle, for example a proton can be represented by $^{1}_{1}\mathrm{p}$. Give the symbols, in this form, for the following particles.

(a) $\overline{p}$ (b) e (c) $\overline{e}$ (d) n (e) $\overline{n}$

3. Copy and complete the table by placing the fermions in the list below in the correct column of the table.

bottom *charm* *down* *electron* *electron neutrino*
muon *muon neutrino* *strange* *tau*
tau neutrino *top* *up*

Quarks	*Leptons*

4.

a. State the difference between a hadron and a lepton in terms of the type of force experienced by each particle.

b. Give one example of a hadron and one example of a lepton.

5. Information on the sign and charge relative to proton charge of six types of quarks (and their corresponding antiquarks) is shown in the table.

Quark name	*Charge relative to size of proton charge*	*Antiquark name*	*Charge relative to size of proton charge*
Up	+2/3	antiup	–2/3
charm	+2/3	anticharm	–2/3
top	+2/3	antitop	–2/3
down	–1/3	antidown	+1/3
strange	–1/3	antistrange	+1/3
bottom	–1/3	antibottom	+1/3

Calculate the charge of the following combinations of quarks:

I. two up quarks and one down quark

II. one up quark and two down quarks

III. two anti-up quarks and one anti-down quark

IV. one anti-up quark and two anti-down quarks.

6. Neutrons and protons are considered to be composed of quarks.

(a) How many quarks are in each neutron and in each proton?

(b) Comment briefly on the different composition of the neutron and proton.

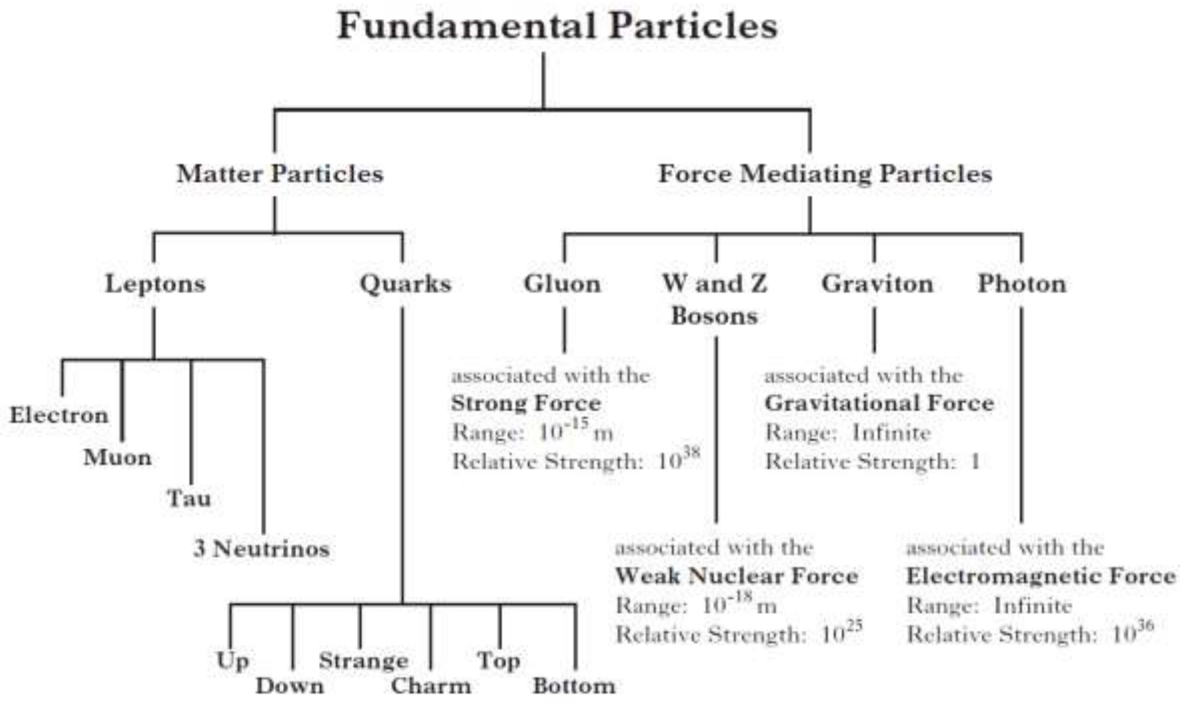
7.

(a) Briefly state any differences between the ‘strong’ and ‘weak’ nuclear forces.

(b) Give an example of a particle decay associated with the weak nuclear force.

(c) Which of the two forces, strong and weak, acts over the greater distance?

26. The following diagram gives information on the Standard Model of Fundamental Particles and Interactions.



Use information from the diagram and your knowledge of physics to answer the following questions.

(*a*) Explain why particles such as leptons and quarks are known as *Fundamental Particles*.

(*b*) A particle called the sigma plus (Σ^+) has a charge of +1. It contains two different types of quark. It has two up quarks each having a charge of +2/3 and one strange quark.
What is the charge on the strange quark?

(*c*) Explain why the gluon cannot be the force mediating particle for the gravitational force.

TUTORIAL 2: ANSWERS FUNDAMENTAL PARTICLES AND INTERACTIONS

1. (a) proton (b) antiproton (c) electron (d) positron
   (e) neutron (f) antineutron (g) neutrino (f) antineutrino

2. (a) ${}^{1}_{-1}\bar{p}$ (b) ${}^{0}_{-1}e$ (c) ${}^{0}_{+1}e$ (d) ${}^{1}_{0}\mathrm{n}$ (e) ${}^{1}_{0}\bar{n}$

3.

Quarks	*Leptons*
bottom	**electron**
charm	**electron neutrino**
down,	**muon**
strange	**muon neutrino**
top	**tau**
up	**tau neutrino**

4. (a) Leptons are particles that are acted on by the weak nuclear force but not by the strong nuclear force. Hadrons are particles that are acted on by the weak and strong nuclear force.
(b) Leptons – any one of electron, electron neutrino, muon, muon neutrino, tau and tau neutrino. Hadron (made up of quarks) – proton, neutron, pi meson.

5. (a) +e
(b) 0
(c) –e
(d) 0

6. (a) 3
(b) For the neutron the three quarks must give a charge of zero. For the proton the three quarks must give a charge of +e.

7. (a) Strong force has a range of less than 10^{-14} m; weak force has a range of less than 10^{-17} m.
(b) Beta decay
(c) Strong force.

Exam Question

(a) These particles cannot be broken down into other sub atomic particles
(KEY POINT) it is not that they can be used to make bigger things but rather that they are not made from smaller things

(b) For the sigma plus particle

$$2 \times (+\tfrac{2}{3}) + q_s = +1$$

$$q_s = - -\tfrac{1}{3}$$

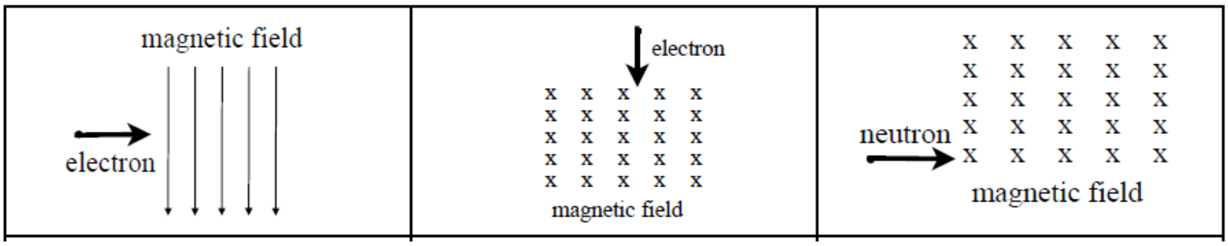
Charge on the strange quark = $-\frac{1}{3}$

(c) Strong force (associated with the gluon) acts over a very short distance, the gravitational force extends over very large / infinite distances

CHAPTER 4 FORCES ON CHARGED PARTICLES

TUTORIAL 1- MOVEMENT IN A MAGNETIC FIELD

1. Copy the diagrams below and describe the movement of the particle in the magnetic field.



b) Using the same magnetic fields as shown above replace each of the particles with an alpha particle. Describe the motion of the alpha particle due to the force from each field.

2. 1996 Credit Physics Paper

(a) A current carrying wire is placed between the poles of a magnet. The direction of the electron current in the wire is as indicated in Figure 1. The conductor experiences an upward force as shown in Figure 1.

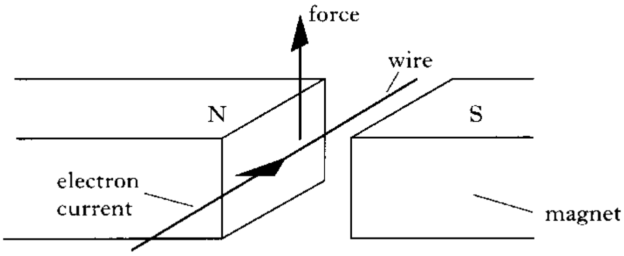


figure 1

State the rule that determines the direction of the Force on the wire.

(b) Figures 2 and 3 show other current carrying wires placed between the poles of the magnets. In each case, copy out the diagrams and indicate on figures 2 and 3 the direction of the force on the wire.

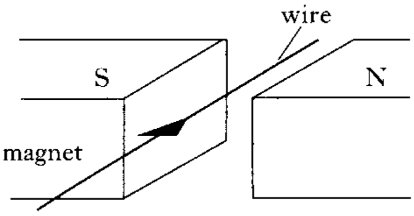


figure 2

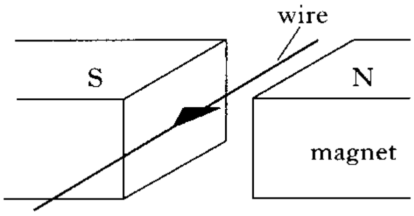


figure 3

(c) Figure 4 shows a simple electric motor with a coil WXYZ free to spin about a shaft PQ.

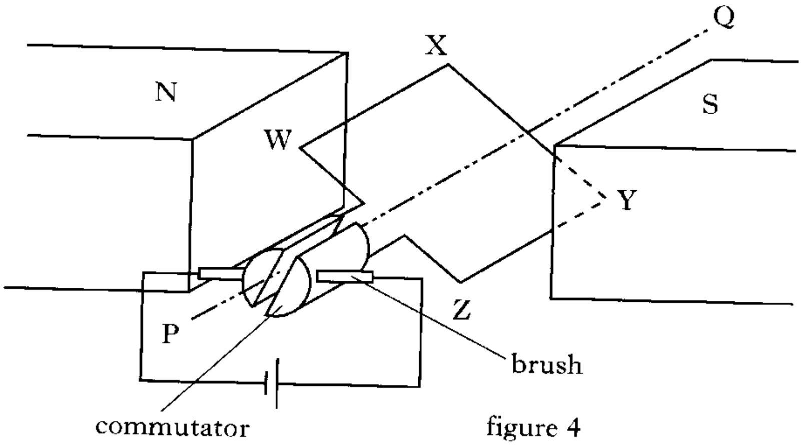


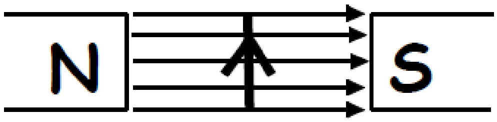
figure 4

(i) By looking at the diagram and using the conclusions you reached in part b) copy out the diagram and mark on your Figure 4
   1. The direction of the electron current in the coil;
   2. The directions of the forces on the coil;
   3. The direction of the rotation of the coil.

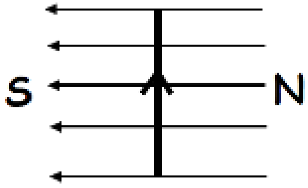
(d) In commercial motors, explain why;
   (i) More than one rotating coil is used;
   (ii) Field coils rather than permanent magnets are used

3. An electron travels from west to east and passes into in a horizontal magnetic field directed towards the north.
   (a) Draw a labelled sketch to show this situation from above.
   (b) State the direction of the force on the electrons in the wire.

4. An electron is directed at 90° (right-angles) to the magnetic field lines of a horseshoe magnet . The diagram shows the view from above the magnet. State the direction of the magnetic force.



5. The diagram shows from above a 0.1 m straight, horizontal length of metal wire which has been placed perpendicular (at 90°) to a horizontal magnetic field.



State the direction of the force on the electrons in the wire

6. An electron travels from south to north in a horizontal magnetic field directed from east to west.

(a) Draw a labelled sketch to show this situation from above.

(b) State the direction of the force.

7. A proton is placed parallel to a horizontal magnetic field.
   a. Draw a diagram of the set up
   b. State the direction of the force which acts on the proton.

TUTORIAL 2 FORCES ON CHARGED PARTICLES

In the following questions, when required, use the following data:

Charge on electron = $-1{\cdot}60 \times 10^{-19}$ C ***Mass of electron = $9{\cdot}11 \times 10^{-31}$ kg***

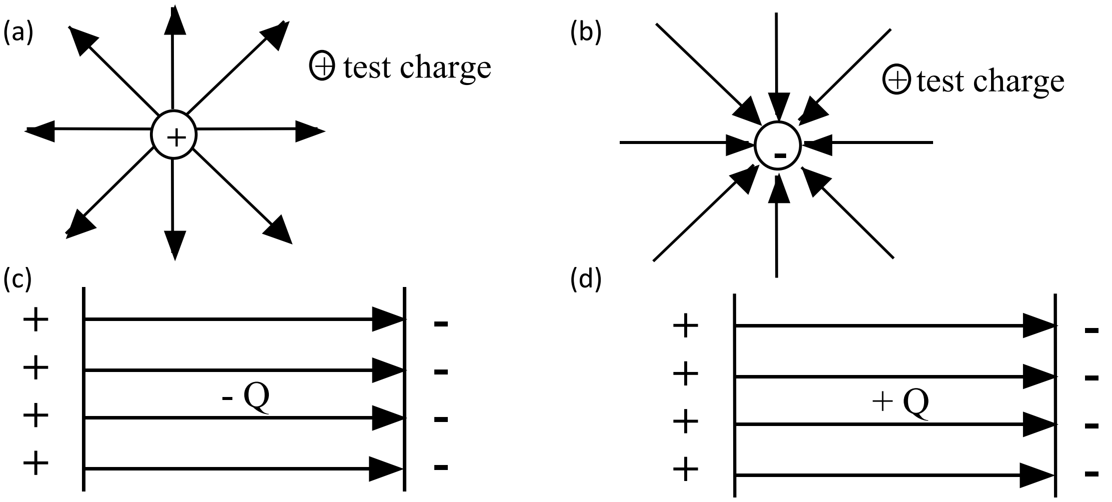
Charge on proton = $1{\cdot}60 \times 10^{-19}$ C ***Mass of proton = $1{\cdot}67 \times 10^{-27}$ kg***

ELECTRIC FIELDS

1. Draw the electric field pattern for the following point charges and pair of charges:

(a) (b) (c)

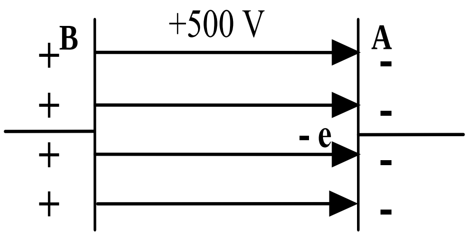
2. Describe the motion of the small positive test charges in each of the following fields.



3. An electron volt (eV) is a unit of energy. It represents the change in potential energy of an electron that moves through a potential difference of 1 V. What is the equivalent energy of 1 eV in joules?

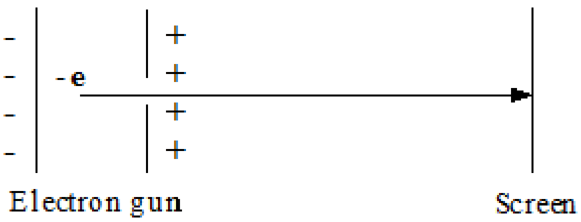
4. An electron has energy of 5 MeV. Calculate its energy in joules.

5. The diagram shows an electron accelerates between two parallel conducting plates A and B. The p.d. between the plates is 500 V.



(a) Calculate the electrical work done in moving the electron from plate A to plate B.
(b) How much kinetic energy has the electron gained in moving from A to B?
(c) What is the speed of the electron just before it reaches plate B?

6. Electrons are 'fired' from an electron gun at a screen.

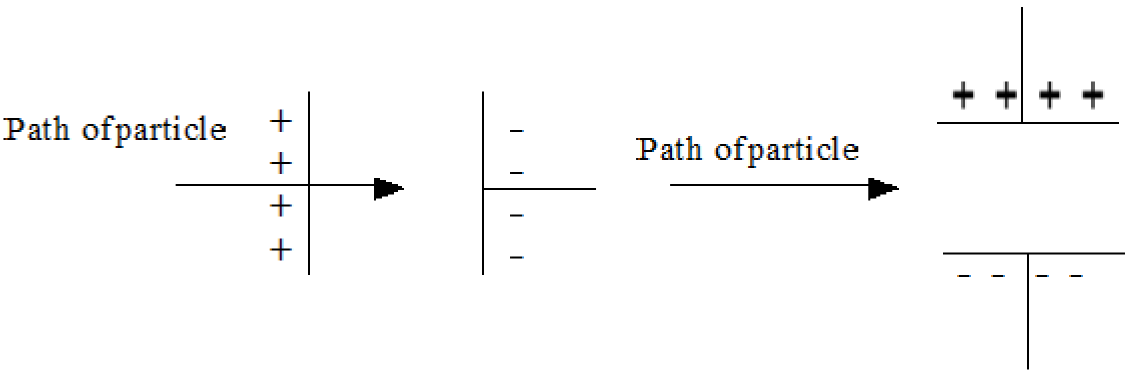


The p.d. across the electron gun is 2000 V.
The electron gun and screen are in a vacuum.
After leaving the positive plate the electrons travel at a constant speed to the screen.
Calculate the speed of the electrons just before they hit the screen.

7. A proton is accelerated from rest across a p.d. of 400 V. Calculate the increase in speed of the proton.

8. In an X-ray tube electrons forming a beam are accelerated from rest and strike a metal target. The metal then emits X-rays. The electrons are accelerated across a p.d. of 25 kV. The beam of electrons forms a current of 3·0 mA.
(a) (i) Calculate the kinetic energy of each electron just before it hits the target.
(ii) Calculate the speed of an electron just before it hits the target.
(iii) Find the number of electrons hitting the target each second.
(b) What happens to the kinetic energy of the electrons?

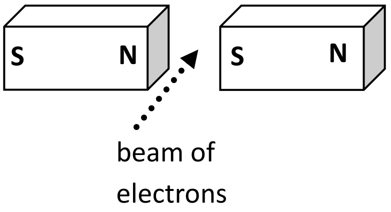
9. Sketch the paths which
(a) an alpha-particle, (b) a beta-particle, (c) a neutron
would follow if each particle, with the same velocity, enters the electric fields shown in the diagrams.



CHARGED PARTICLES IN A MAGNETIC FIELD

1. An electron travelling with a constant velocity enters a region where there is a uniform magnetic field. There is no change in the velocity of the electron. What information does this give about the magnetic field?

2. The diagram shows a beam of electrons as it enters the magnetic field between two magnets.

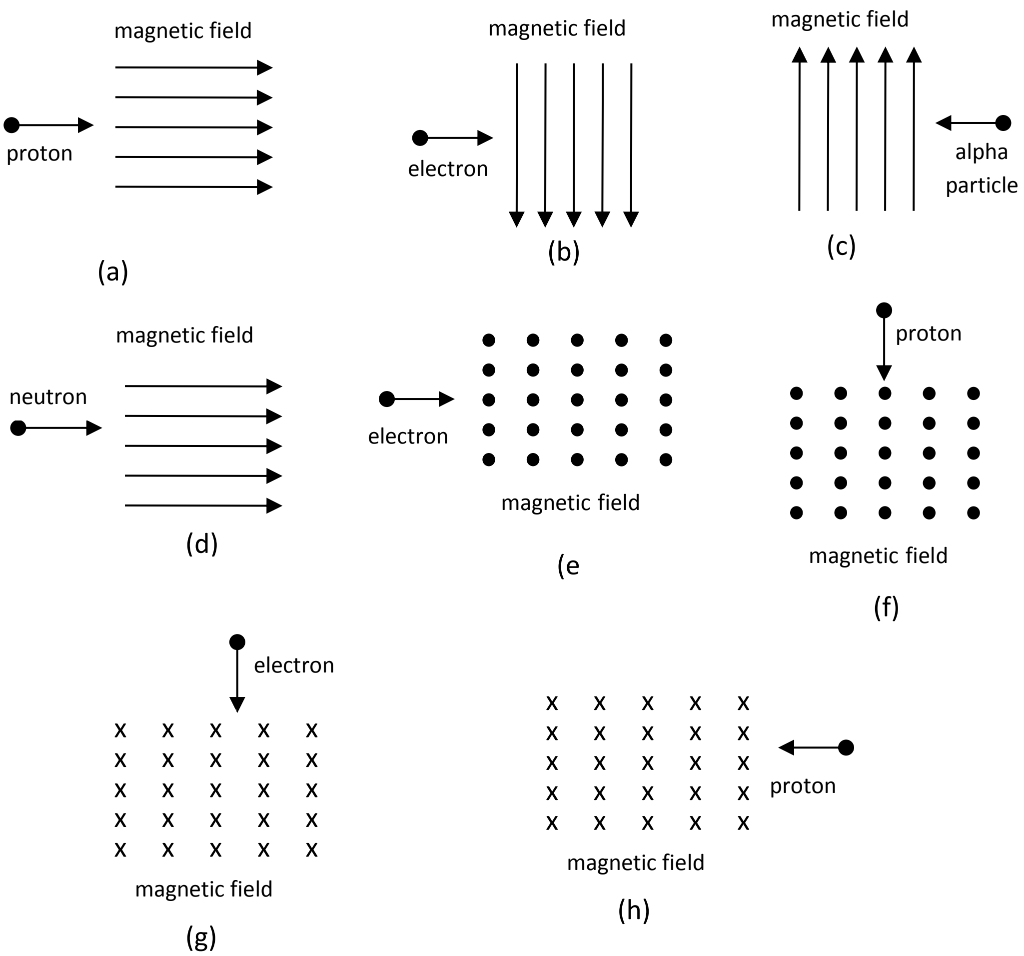


The electrons will:

A be deflected to the left (towards the N pole)
B be deflected to the right (towards the S pole)
C be deflected upwards
D be deflected downwards
E have their speed increased without any change in direction.

3. The diagrams show particles entering a region where there is a uniform magnetic field.

Use the terms: *up, down, into the paper, out of the paper, left, right, no change in direction* to describe the deflection of the particles in the magnetic field.



4. An electron enters a region of space where there is a uniform magnetic field. As it enters the field the velocity of the electron is at right angles to the magnetic field lines.
The energy of the electron does not change although it accelerates in the field.
Use your knowledge of physics to explain this effect.

1. In an evacuated tube, an electron initially at rest is accelerated through a p.d. of 500 V.

(a) Calculate, in joules, the amount of work done in accelerating the electron.

(b) How much kinetic energy has the electron gained?

(c) Calculate the final speed of the electron.

2. In an electron gun, electrons in an evacuated tube are accelerated from rest through a potential difference of 250 V.

(a) Calculate the energy gained by an electron.

(b) Calculate the final speed of the electron.

3. Electrons in an evacuated tube are 'fired' from an electron gun at a screen. The p.d. between the cathode and the anode of the gun is 2000 V. After leaving the anode, the electrons travel at a constant speed to the screen. Calculate the maximum speed at which the electrons will hit the screen.

4. A proton, initially at rest, in an evacuated tube is accelerated between two charged plates A and B. It moves from A, where the potential is 10 kV, to B, where the potential is zero.
Calculate the speed of the proton at B.

5. A linear accelerator is used to accelerate a beam of electrons, initially at rest, to high speed in an evacuated container. The high- speed electrons then collide with a stationary target. The accelerator operates at 2·5 kV and the electron beam current is 3 mA.

(a) Calculate the gain in kinetic energy of each electron.

(b) Calculate the speed of impact of each electron as it hits the target.

(c) Calculate the number of electrons arriving at the target each second.

(d) Give a reason for accelerating particles to high speed and allowing them to collide with a target.

6. The power output of an oscilloscope (cathode-ray tube) is estimated to be 30 W. The potential difference between the cathode and the anode in the evacuated tube is 15 kV.

(a) Estimate the number of electrons striking the screen per second.

(b) Calculate the speed of an electron just before it strikes the screen, assuming that it starts from rest and that its mass remains constant.

7. In an oscilloscope electrons are accelerated between a cathode and an anode and then travel at constant speed towards a screen. A p.d. of 1000 V is maintained between the cathode and anode. The distance between the cathode and anode is $5{\cdot}0 \times 10^{-2}$ cm. The electrons are at rest at the cathode and attain a speed of $1{\cdot}87 \times 10^{7}$ ms^{-1} on reaching the anode. The tube is evacuated.

(a) (i) Calculate the work done in accelerating an electron from the cathode to the anode.

(ii) Show that the average force on the electron in the electric field is $3{\cdot}20 \times 10^{-15}$ N.

(iii) Calculate the average acceleration of an electron while travelling from the cathode to the anode.

(iv) Calculate the time taken for an electron to travel from cathode to anode.

(v) Beyond the anode the electric field is zero. The anode to screen distance is 0·12 cm. Calculate the time taken for an electron to travel from the anode to the screen.

(b) (i) Another oscilloscope has the same voltage but a greater distance between cathode and anode. Would the speed of the electrons be higher, lower or remain at $1{\cdot}87 \times 10^{7}$ ms^{-1}? Explain your answer.

(ii) Would the time taken for an electron to travel from cathode to anode be increased, decreased or stay the same as in (a) (iv)? Explain your answer.

8. In an X-ray tube a beam of electrons, initially at rest, is accelerated through a potential difference of 25 kV. The electron beam then collides with a stationary target. The electron beam current is 5 mA.

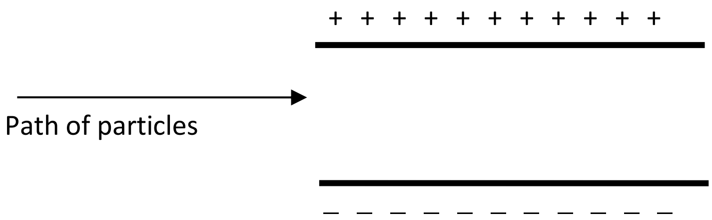
(a) Calculate the kinetic energy of each electron as it hits the target.

(b) Calculate the speed of the electrons at the moment of impact with the target assuming that the electron mass remains constant.

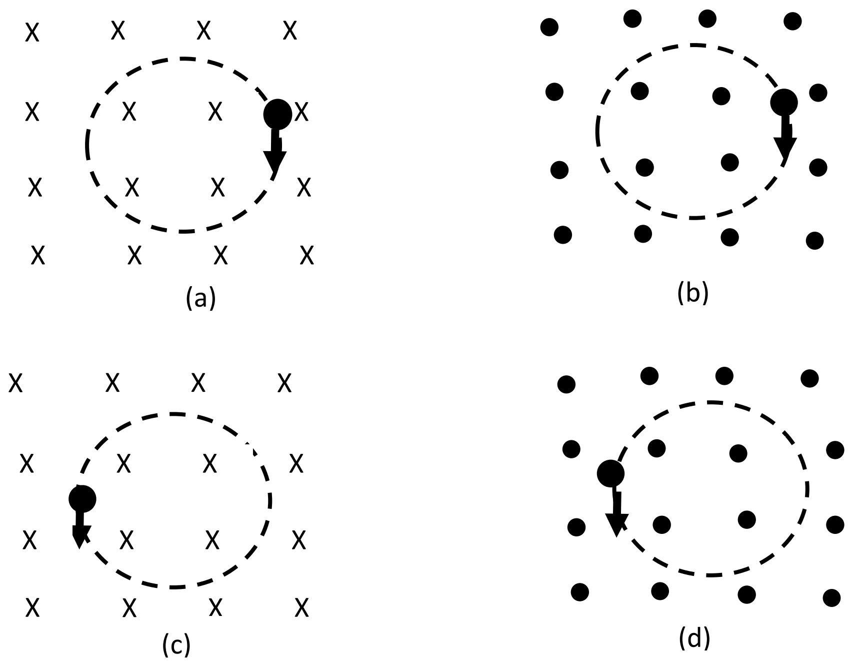
(c) Calculate the number of electrons hitting the target each second.

(d) What happens to the kinetic energy of the electrons?

9. Copy the diagram below and sketch the path that (a) an electron, (b) a proton and (c) a neutron would follow if each particle entered the given electric fields with the same velocity. Label each path.



10. In the following examples identify the charge of particle (positive or negative) which is rotating in a uniform magnetic field. (X denotes magnetic field into page and • denotes magnetic field out of page.)



11. **Answer the following question in your notes jotter as a summary of particle accelerators.** In the following descriptions of particle accelerators, some words and phrases have been replaced by the letters **A** to **R**. Choose the correct word or phrase from the list given for each letter.

In a linear accelerator bunches of charged particles are accelerated by a series of ____**A**____. The final energy of the particles is limited by the length of the accelerator.

This type of accelerator is used in ____**B**____ experiments.

In a cyclotron the charged particles are accelerated by ____**C**____. The particles travel in a ____D____ as a result of a ____**E**____, which is ____**F**____ to the spiral. The radius of the spiral increases as the energy of the particles ____**G**____. The diameter of the cyclotron is limited by the ____**H**____ of the magnet. The resultant energy of the particles is limited by the diameter of the cyclotron and by ____**I**____.

This type of accelerator is used in ____**J**____ experiments.

In a synchrotron bunches of charged particles travel in a ____**K**____ as a result of C shaped magnets whose strength ____**L**____. The particles are accelerated by ____**M**____.

As the energy of the particles increases the strength of the magnetic field is ____**N**____ to maintain the radius of the path of the particles. In synchrotron accelerators the particles can have, in theory, an unlimited series of accelerations as the particles can transit indefinitely around the ring. There will be a limit caused by ____**O**____.

In this type of accelerator particles with ____**P**____ mass and ____**Q**____ charge can circulate in opposite directions at the same time before colliding. This increases the energy of impact. This type of accelerator is used in ____**R**____ experiments.

From the table below choose the correct words or phrases to replace the letters.

Letter	*List of replacement word or phrase*
A, C, E, M	constant magnetic field, alternating magnetic fields, alternating electric fields, constant electric fields
B, J, R	colliding-beam, fixed-target
D, K	spiral of decreasing radius, spiral of increasing radius, circular path of fixed radius
F	perpendicular, parallel
G	decreases, increases
H	physical size, strength
I, O	gravitational effects, relativistic effects
L	can be varied, is constant
N	decreased, increased
P, Q	the same, different

FORCES ON CHARGED PARTICLE TUTORIAL ANSWERS

TUTORIAL 1 – MOTION IN FIELDS

1

- **a)** (i) The electron will curve out of the page. (ii) The electron will curve to its right. (to the left as we look at it) (iii) There will be no change in the direction of the particle as the neutron has no charge.
- **b)** (i) The alpha particle will curve into the page (ii) The alpha particle will curve to its left (to the right as we look at it). (iii) the alpha particle will move upwards

2.

(a) This obey's the Right hand motor rule or the left hand slap rule

(b) In figure 2 the force should be drawn acting vertically downwards, in figure 3 the force should be drawn acting vertically upwards.

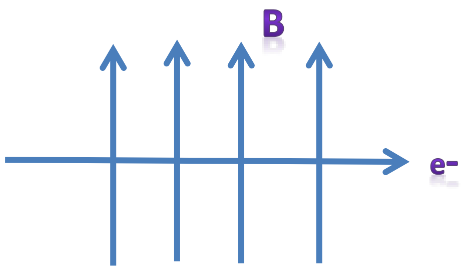
(c) 1 The electron current should be shown in the directions of WXYZ round the coil.

2 The force on WX is drawn acting vertically upwards. The force on YZ is drawn acting vertically downwards.

3. When viewed along the direction PQ the coil rotates in a clockwise direction.

(d,ii) More coils allows for smoother rotation, (ii) Allows for the motor to work on a.c.

3 (a)



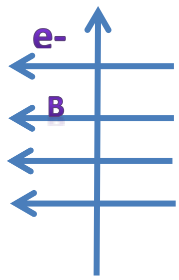
(b)

The force is directed into the page.

4. Out of the page

5. into the page

6.



(a)

(b) Into the page

7.

There will be no force on the alpha particle as it is travelling parallel to the magnetic field.

TUTORIAL ANSWERS

Electric fields

3. $1{\cdot}6 \times 10^{-19}$ J

4. $8{\cdot}0 \times 10^{-13}$ J

5. (a) $8{\cdot}0 \times 10^{-17}$ J , (b) $8{\cdot}0 \times 10^{-17}$ J, (c) $1{\cdot}3 \times 10^{7}$ m s^{-1}¶

6. $2{\cdot}65 \times 10^{7}$ m s^{-1}

7. $2{\cdot}76 \times 10^{5}$ m s^{-1}

8. (a) (i) $4{\cdot}0 \times 10^{15}$ J , (ii) $9{\cdot}4 \times 10^{7}$ m s^{-1} , (iii) $1{\cdot}9 \times 10^{16}$

Charged particles in a magnetic field

1. Magnetic field is in the same plane and in the same or opposite direction to the velocity of the electron.

2. C: be deflected upwards

3. (a) no change in direction, (b) out of the paper , (c) into the paper

   (d) no change in direction (e) up, (f) left

   (g) left , (h) down

Particle accelerators

1. (a) 8×10^{-17} J , (b) 8×10^{-17} J , (c) $1{\cdot}33 \times 10^{7}$ m s^{-1}

2. (a) 4×10^{-17} J , (b) $9{\cdot}37 \times 10^{6}$ m s^{-1}

3. $2{\cdot}65 \times 10^{7}$ m s^{-1}

4. $1{\cdot}38 \times 10^{6}$ m s^{-1}

5. (a) 4×10^{-16} J , (b) $2{\cdot}96 \times 10^{7}$ m s^{-1} , (c) $1{\cdot}88 \times 10^{16}$

6. (a) $1{\cdot}25 \times 10^{16}$, (b) $7{\cdot}26 \times 10^{7}$ m s^{-1}

7. (a) (i) $1{\cdot}6 \times 10^{-16}$ J

   (iii) $3{\cdot}51 \times 10^{15}$ m s^{-2}

   (iv) $5{\cdot}34 \times 10^{-9}$ s

   (v) $6{\cdot}42 \times 10^{-9}$ s

   (b) (i) Same since *Q* and *V* same

   (ii) Longer since acceleration is smaller

8. (a) $4{\cdot}0 \times 10^{-15}$ J , (b) $9{\cdot}37 \times 10^{7}$ m s^{-1}, (c) $3{\cdot}12 \times 10^{16}$

   (d) Heat and X-rays are produced

9. (a) Electron accelerated towards positive plate

(b) Proton accelerated towards negative plate but less curved than that of electron

(c) Neutron straight through.

10. (a) Negative , (b) Positive , (c) Positive, (d) Negative

11. A = alternating electric fields; B = fixed-target; C = alternating electric fields; D = spiral of increasing radius; E = constant magnetic field; F = perpendicular; G = increases; H = physical size; I = relativistic effects; J = fixed-target; K = circular path of fixed radius; L = can be varied; M = alternating magnetic fields; N = increased; O = relativistic effects; P = the same; Q = opposite; R = colliding beam.

CHAPTER 5: NUCLEAR REACTIONS

NUCLEAR REACTIONS/TUTORIAL 1

1) Why is swallowing an alpha particle source more dangerous than a gamma ray source since alpha particles are less penetrating than gammas?

2) Using a Periodic Table, put the following nuclear equations into words:-

$$(a) \quad {}^{234}_{91}Pa \rightarrow {}^{234}_{92}U + {}^{0}_{-1}e + \gamma$$

$$(b) \quad {}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He + \gamma$$

$$(c) \quad {}^{222}_{86}Rn \rightarrow {}^{218}_{84}Po + {}^{4}_{2}He$$

3) Name the particles emitted in each of the following disintegrations:-

$$(a) \quad {}^{214}_{83}\mathrm{Bi} \rightarrow {}^{214}_{84}\mathrm{Po} + \text{particle} + \gamma$$

$$(b) \quad {}^{214}_{84}\mathrm{Po} \rightarrow {}^{210}_{82}\mathrm{Pb} + \text{particle}$$

$$(c) \quad {}^{210}_{82}\mathrm{Pb} \rightarrow {}^{210}_{83}\mathrm{Bi} + \text{particle}$$

4) What are the missing numbers in each of the following, and in each case, identify element X?

$$(a) \quad {}^{234}_{91}Pa \rightarrow X + {}^{0}_{-1}e$$

$$(b) \quad {}^{234}_{92}U \rightarrow X + {}^{4}_{2}He$$

5) The atomic mass of ${}^{14}_{7}\mathrm{N}$ is 23.252x10^{-27} kg and the *sum* of the atomic masses of ${}^{1}_{1}\mathrm{H}$ and ${}^{13}_{6}\mathrm{C}$ is 23.265x10^{-27} kg.

Does ${}^{1}_{1}\mathrm{H} + {}^{13}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N}$ give out energy? Justify your answer.

TUTORIAL 2 (SCET) NUCLEAR REACTIONS

FISSION AND FUSION

1) Use a periodic table to identify the elements that have these atomic numbers:

   (a) 6 (b) 25 (c) 47 (d) 80 (e) 86 (f) 92

2) The list shows the symbols for six different isotopes.

   (i) $^{7}_{3}\mathrm{Li}$ (ii) $^{64}_{30}\mathrm{Zn}$ (iii) $^{109}_{47}\mathrm{Ag}$

   (iv) $^{131}_{54}\mathrm{Xe}$ (v) $^{239}_{94}\mathrm{Pu}$ (vi) $^{257}_{103}\mathrm{Lw}$

   For each of the isotopes state:

   (a) the number of protons

   (b) the number of neutrons.

3) The incomplete statements below illustrate four nuclear reactions.

   $^{228}_{90}\mathrm{Th} \rightarrow {}^{224}_{88}\mathrm{Ra} + \mathrm{A}$ $^{220}_{86}\mathrm{Rn} \rightarrow {}^{4}_{2}\mathrm{He} + \mathrm{B}$

   $^{211}_{82}\mathrm{Pb} \rightarrow {}^{211}_{83}\mathrm{Bi} + \mathrm{C}$ $\mathrm{D} \rightarrow {}^{219}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$

   Identify the missing particles or nuclides represented by the letters A, B, C and D.

4) Part of a radioactive decay series is represented below:

   $$^{235}_{92}\mathrm{U} \rightarrow {}^{231}_{90}\mathrm{Th} \rightarrow {}^{231}_{91}\mathrm{Pa} \rightarrow {}^{227}_{89}\mathrm{Ac}$$

   Identify the particle emitted at each stage of the decay.

   Such a series does not always give a complete picture of the radiations emitted by each nucleus. Give an explanation why the picture is incomplete.

5) For a particular radionuclide sample 8×10^{7} disintegrations take place in 40 s. Calculate the activity of the source.

6) How much energy is released when the following 'decreases' in mass occur in various fission reactions?

   (a) $3{\cdot}25 \times 10^{-28}$ kg (b) $2{\cdot}01 \times 10^{-28}$ kg (c) $1{\cdot}62 \times 10^{-28}$ kg

   (d) $2{\cdot}85 \times 10^{-28}$ kg

7) The following statement represents a nuclear reaction involving the release of energy.

   $$^{3}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$$

   The masses of these particles are given below.

   Mass of $^{3}_{1}\mathrm{H}$ = $5{\cdot}00890 \times 10^{-27}$ kg

   Mass of $^{2}_{1}\mathrm{H}$ = $3{\cdot}34441 \times 10^{-27}$ kg

   Mass of $^{4}_{2}\mathrm{He}$ = $6{\cdot}64632 \times 10^{-27}$ kg

   Mass of $^{1}_{0}\mathrm{n}$ = $1{\cdot}67490 \times 10^{-27}$ kg

   (a) Explain, using $E=mc^2$, how this nuclear reaction results in the production of energy. Calculate the decrease in mass that occurs when this reaction takes place.

   (b) Calculate the energy released in this reaction.

   (c) What is the name given to this type of nuclear reaction?

(d) Calculate the number of reactions required each second to produce a power of 25 MW.

8) Plutonium can undergo the nuclear reaction represented by the statement below:

$$^{239}_{94}\mathrm{Pu} + {}^{1}_{0}\mathrm{n} = \mathrm{Te} + {}^{100}_{42}\mathrm{Mo} + 3\,{}^{1}_{0}\mathrm{n}$$

The masses of the nuclei and particles involved in the reaction are as follows.

Particle	*n*	*Pu*	*Te*	*Mo*
Mass/kg	$1{\cdot}675 \times 10^{-27}$	$396{\cdot}741 \times 10^{-27}$	$227{\cdot}420 \times 10^{-27}$	$165{\cdot}809 \times 10^{-27}$

(a) What kind of reaction is represented by the statement?
(b) State the mass number and atomic number of the nuclide Te in the reaction.
(c) Calculate the decrease in mass that occurs in this reaction.
(d) Calculate the energy released in this reaction.

9) Neon has two main isotopes, $^{20}_{10}\mathrm{Ne}$ and $^{22}_{10}\mathrm{Ne}$, and has a relative atomic mass of 20.2.

What does this indicate about the relative abundance of each isotope?

TUTORIAL ANSWERS:

TUTORIAL 1 ANSWERS

1. The swallowed a source causes a lot of damaging ionisation in its vicinity and at the same time manages to conceal its location from the helpful surgeons because the emitted α's are absorbed before they get through the skin and reach the detectors used for pin-pointing their location.
2. (a) Protactinium 234 decays to uranium 234 by emitting a β particle and γ radiation.
   (b) The 238 isotope of uranium disintegrates by giving out an α particle and γ radiation to leave thorium 234.
   (c) Radon 222 emits an α particle to leave polonium 218 as its daughter product.
3. (a) A β-particle.
   (b) α
   (c) β
4. (a) $^{234}_{92}\mathrm{X}$
   (b) $^{230}_{90}\mathrm{X}$
5. yes

TUTORIAL 2 ANSWERS FISSION AND FUSION

2. (i) (a) 3 (b) 4
   (ii) (a) 30 (b) 34
   (iii) (a) 47 (b) 62
   (iv) (a) 54 (b) 77
   (v) (a) 94 (b) 145
   (vi) (a) 103 (b) 154
3. A is $^{4}_{2}\mathrm{He}$ or α

   B is $^{216}_{84}\mathrm{Po}$

   C is $^{0}_{-1}e$ or β

   D is $^{223}_{88}\mathrm{Ra}$

4. α then β then α

5. $A = 2 \times 10^6$ Bq

6. (a) $2{\cdot}93 \times 10^{-11}$ J
(b) $1{\cdot}81 \times 10^{-11}$ J
(c) $1{\cdot}46 \times 10^{-11}$ J
(d) $2{\cdot}57 \times 10^{-11}$ J

7. (a) $3{\cdot}209 \times 10^{-29}$ kg
(b) $2{\cdot}89 \times 10^{-12}$ J
(d) $8{\cdot}65 \times 10^{18}$

8. (b) mass number 136, atomic number 52
(c) $1{\cdot}62 \times 10^{-28}$ kg
(d) $1{\cdot}46 \times 10^{-11}$ J

TUTORIAL ANSWERS NUCLEAR REACTIONS

4. i) 3, 4 ii) 30, 34 iii) 47, 62 iv) 54, 77 v) 94, 145 vi) 103, 154.

A α B $^{216}_{84}\mathrm{Po}$ C β D $^{223}_{88}\mathrm{Ra}$

6. α, β, α.
8. 2.0×10^6 Bq.
9. 1/8th.
10. 6c.p.s.
11. a) 2.925×10^{-11} J b) 1.809×10^{-11} J c) 1.458×10^{-11} J
d) 2.565×10^{-11} J.
12. a) 0.025×10^{-27} kg b) 2.25×10^{-12} J.
13. a) mass no. 137 atomic no. 52
b) 0.162×10^{-27} kg
c) 1.458×10^{-11}J

CHAPTER 6: WAVE PARTICLE DUALITY

TUTORIAL 1

Photoelectric Effect

1. What is the energy of a photon from a beam of light with a frequency of 700THz?
2. What frequency of light has photons with an individual energy of 3×10^{-19} joules?
3. A light beam consists of red and green light whose photons carry energies of either 2.97×10^{-19} J, or 3.43×10^{-19}J. Which photon is associated with which colour?
4. If the work function of a metal is 5×10^{-19} joules, what is its threshold frequency?
5.
   a. What is the maximum possible kinetic energy of a photo-electron ejected by light of frequency 10^{15}Hz?
   b. If the ejected electron in (a) above (charge 1.6×10^{-19}C), moves against a p.d. of half a volt, how much kinetic energy is it left with?
6. What effect does it have on the appearance of a spectrum if one particular energy level change is more likely than any of the others so that it occurs more frequently?
7. What do the symbols stand for in each of the following equations?

a) $E = hf$

b) $hf = hf_0 + E_K$

c) $hf = W_2 - W_1$

TUTORIAL 1 PHOTOELECTRIC EFFECT ANSWERS

Photoelectric Effect

1.

$$E = hf \quad \Rightarrow \quad E = 6.63\times10^{-34}\times700\times10^{12} = 4.64\times10^{-19}$$

The photon has an energy of 4.64×10^{-19} joules.

2.

$$E = hf \quad \Rightarrow \quad 3\times10^{-19} = 6.63\times10^{-34}\times f \quad \Rightarrow \quad f = 4.52\times10^{14}$$

The light's frequency is 452 THz

3. The red light has a lower frequency than the green and so its individual photons carry less energy. 2.97×10^{-19} J = RED, or 3.43×10^{-19}J = GREEN.

4. $$f_o = \frac{E}{h} \Rightarrow f_o = \frac{5\times10^{-19}}{6.63\times10^{-34}} = 7.54\times10^{14}$$ The threshold frequency is 754THz

5.

a) The energy of a photon from light of frequency 10^{15} Hz is given by:

$$E = hf = 6\cdot63\times10^{-34}\times10^{15} = 6\cdot63\times10^{-34}\ J$$

The greatest available kinetic energy occurs when the work function of the surface is zero. In this situation, the maximum kinetic energy equals the energy of the incoming photon, $6.63\text{x}10^{-19}$J

b) The energy change involved when a charge moves through a p.d. is given by :

$$E = QV = 1\cdot6\times10^{-19}\times0\cdot5$$
$$E = 0\cdot8\times10^{-19}$$
$$\text{Energy remaining } = 6\cdot63\times10^{-19} - 0\cdot8\times10^{-19}$$
$$= 5\cdot83\times10^{-19}\ J$$

6. It will be brighter than the other spectra.

7.

a) E, energy (J); h, Planck's constant (J s); f, frequency (Hz)

b) h, Planck's constant (J s); f, frequency (Hz); hf_0, work function (J); E_K, kinetic energy (J).

c) h, Planck's constant (J s); f, frequency (Hz); $W_{1/2}$, energy levels (J).

TUTORIAL 2

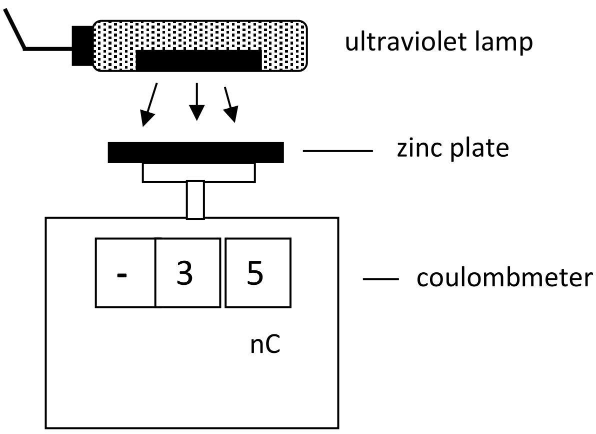
Wave-particle duality

1. A 'long wave' radio station broadcasts on a frequency of 252 kHz.
   (a) Calculate the period of these waves.
   (b) What is the wavelength of these waves?
2. Green light has wavelength 546 nm.
   (a) Express this wavelength in metres (using scientific notation).
   (b) Calculate:
      (i) the frequency of these light waves
      (ii) the period of these light waves.
3. Ultraviolet radiation has a frequency $2\cdot0\times10^{15}$ Hz.
   (a) Calculate the wavelength of this radiation.
   (b) Calculate the period of this radiation.
4. Blue light has a frequency of $6\cdot50\times10^{14}$ Hz. Calculate the energy of one photon of this radiation.

5. Red light has a wavelength of $6\cdot44\times10^{-7}$ m. Calculate the energy of one photon of this light.

6. A photon of radiation has an energy of 3·90 × 10^5 J. Calculate the wavelength of this radiation in nm.

7. In an investigation into the photoelectric effect a clean zinc plate is attached to a coulombmeter, as shown.



The threshold frequency of radiation for zinc is 6·50 × 10^{14} Hz.

(a) The zinc plate is initially negatively charged.

A lamp is used to shine ultraviolet radiation of frequency 6·7 × 10^{14} Hz onto the zinc plate. Describe and explain what happens to the reading on the coulombmeter.

(b) The zinc plate is again negatively charged.

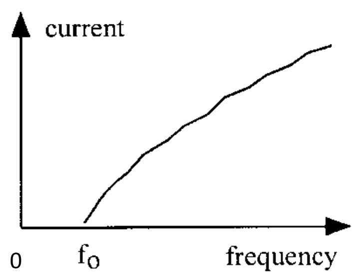
Describe and explain the effect each of the following changes has on the reading on the coulombmeter:

(i)moving the ultraviolet lamp further away from the zinc plate

(ii)using a source of red light instead of the uv lamp.

(c) The zinc plate is now positively charged. The uv lamp is again used to irradiate the zinc plate. Describe and explain the effect this has on the positive reading on the coulombmeter.

8. In a study of photoelectric currents, the graph shown was obtained.



(a) What name is given to the frequency f_o?

(b) Explain why no current is detected when the frequency of the incident radiation is less than f_o.

9. For a certain metal, the energy required to eject an electron from the atom is 3·30 × 10^{-19} J.

(a) Calculate the minimum frequency of radiation required to emit a photoelectron from the metal.

(b) Explain whether or not photoemission would take place using radiation of:

(i) frequency 4 × 10^{14} Hz

(ii) wavelength 5 × 10^{-7} m.

10. The minimum energy required to remove an electron from zinc is 6·10 × 10^{-19} J.

(a) What is the name is given to this minimum energy?

(b) Calculate the value of f_0 for zinc.

(c) Photons with a frequency of $1{\cdot}2 \times 10^{15}$ Hz strike a zinc plate, causing an electron to be ejected from the surface of the zinc.
Calculate the amount of energy the electron has after it is released from the zinc.

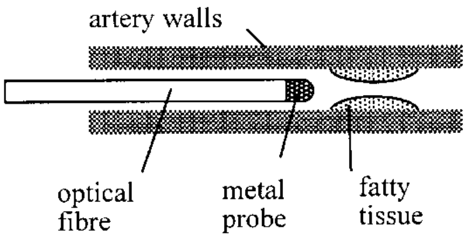
(d) What kind of energy does the electron have after it is released?

11. Radiation of frequency $5{\cdot}0 \times 10^{14}$ Hz can eject electrons from a metal surface.

(a) Calculate the energy of each photon of this radiation.

(b) Photoelectrons are ejected from the metal surface with a kinetic energy of $7{\cdot}0 \times 10^{-20}$ J. Calculate the work function of this metal.

12. An argon laser is used in medicine to remove fatty deposits in arteries by passing the laser light along a length of optical fibre. The energy of this light is used to heat up a tiny metal probe to a sufficiently high temperature to vaporise the fatty deposit.

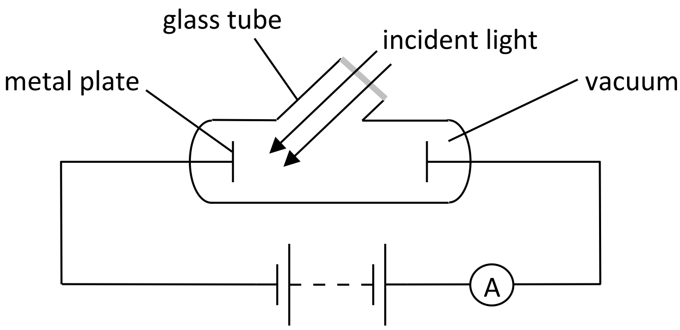


The laser has a power of 8·0 W. It emits radiation with a wavelength of 490 nm.

(a) How much energy is delivered from the laser in 5 s?

(b) Calculate the number of photons of this radiation required to provide the 5 s pulse of energy from the 8·0 W laser.

13. The apparatus shown is used to investigate photoelectric emission from a metal plate when electromagnetic radiation is shone on the plate.
The irradiance and frequency of the incident radiation can be varied as required.



(a) Explain what is meant by 'photoelectric emission' from a metal.

(b) What is the name given to the minimum frequency of the radiation that produces a current in the circuit?

(c) A particular source of radiation produces a current in the circuit. Explain why the current in the circuit increases as the irradiance of the incident radiation increases.

14. State whether each of the following statements is true or false.

(a) Photoelectric emission from a metal occurs only when the frequency of the incident radiation is greater than the threshold frequency for the metal.

(b) The threshold frequency depends on the metal from which photoemission takes place.

(c) When the frequency of the incident radiation is greater than the threshold frequency for a metal, increasing the irradiance of the radiation will cause photoemission from the metal to increase.

(d) When the frequency of the incident radiation is greater than the threshold frequency for a metal, increasing the irradiance of the radiation will increase the maximum energy of the electrons emitted from the metal.

(e) When the frequency of the incident radiation is greater than the threshold frequency for a metal, increasing the irradiance of the incident radiation will increase the photoelectric current from the metal.

TUTORIAL 2 WAVE PARTICLE DUALITY ANSWERS

1.

a) $$T = \frac{1}{f} = \frac{1}{252 \times 10^3} = 3.97 \times 10^{-6}\, s$$

b) $$\lambda = \frac{v}{f} = \frac{3 \times 10^8}{252 \times 10^3} = 1190.5m$$

2.

a) 0.546 μm.

b) 5.46 x 10^{-7} m

c) $$f = \frac{v}{\lambda} = \frac{3 \times 10^8}{5.46 \times 10^{-7}} = 5.49 \times 10^{14}\, Hz$$

$$T = \frac{1}{f} = \frac{1}{5.49 \times 10^{14}} = 1.82 \times 10^{-15}\, s$$

7.

a) Electrons on the gold leaf and its support repel each other, making the gold leaf rise.

b) The gold leaf gradually falls back down. As electrons are ejected from the zinc plate the overall charge on the electroscope gradually reduces and so the repulsive force gradually decreases.

c)

i) The gold leaf falls back more rapidly since electrons are ejected more rapidly.

ii) The gold leaf falls back more slowly since electrons are ejected more slowly.

iii) The gold leaf remains risen. No electrons are ejected as the radiation cannot eject electrons.

iv) The gold leaf remains risen. No electrons are ejected as the radiation cannot eject electrons.

v) The leaf would rise further. As electrons are ejected the charge on it becomes more positive.

8.

a) Threshold frequency

b) Below the threshold frequency there is not enough energy in the incoming radiation to cause movement of electrons between energy levels.

9.

a)
$$E = hf$$
$$3\cdot 3\times 10^{-19} = 6\cdot 63\times 10^{-34}\, f$$
$$f = \frac{3\cdot 3\times 10^{-19}}{6\cdot 63\times 10^{-34}} = 4\cdot 98\times 10^{14}\ Hz$$

b)

i) No, this would not provide enough energy.

ii)
$$f = \frac{v}{\lambda} = \frac{3\times 10^{8}}{5\times 10^{-7}} = 0\cdot 6\times 10^{15}\ Hz$$
This is greater than the threshold frequency so emission would occur.

10.

a) Work function.

b)
$$E = hf$$
$$6\cdot 1\times 10^{-19} = 6\cdot 63\times 10^{-34}\, f$$
$$f = \frac{6\cdot 1\times 10^{-19}}{6\cdot 63\times 10^{-34}} = 9\cdot 20\times 10^{14}\ Hz$$

c)

i)
$$E = hf$$
$$E = 6\cdot 63\times 10^{-34}\times 1\cdot 20\times 10^{15}$$
$$E = 7\cdot 96\times 10^{-19} J$$
$$\therefore \text{Extra energy} = 7\cdot 96\times 10^{-19} - 6\cdot 10\times 10^{-19}$$
$$= 1.86\times 10^{-19}\ J$$

ii) Kinetic energy

11.

$$E = hf$$
$$E = 6\cdot 63\times 10^{-34}\times 5\cdot 0\times 10^{14}$$
$$E = 3\cdot 32\times 10^{-19} J$$
$$E = W + E_K$$
$$3\cdot 32\times 10^{-19} = W + 7\cdot 0\times 10^{-20}$$
$$W = 3\cdot 32\times 10^{-19} - 7\cdot 0\times 10^{-20}$$
$$W = 2\cdot 62\times 10^{-19}\ J$$

12.

a)
$$E = Pt$$
$$E = 8 \times 5 = 40\, J$$

$$E_{electron} = \frac{hc}{\lambda} = \frac{6 \cdot 63 \times 10^{-34} \times 3 \times 10^{8}}{490 \times 10^{-9}} = 4 \cdot 06 \times 10^{-19}\, J$$

$$\therefore \text{number of electrons} = \frac{40}{4 \cdot 06 \times 10^{-19}} = 0.98 \times 10^{20}$$

13.

a) Emission spectrum.

b) Each line corresponds to a specific jump between energy levels which produces a single wavelength of radiation.

c)
$$E = \frac{hc}{\lambda} = \frac{6 \cdot 63 \times 10^{-34} \times 3 \times 10^{8}}{680 \times 10^{-9}} = 2 \cdot 93 \times 10^{-19}\, J$$

d) A continuous spectrum would be observed.

CHAPTER 7: INTERFERENCE AND DIFFRACTION

TUTORIAL 1: WAVES

1 A harbour has two openings in its walls and a boat is moored 200m from one and 240m from the other. If the average wavelength is 1.6m, is the boat at a position of constructive or destructive interference?

2 Two synchronized sets of drips fall from an overhead gutter into a puddle. The centres of the two sets of waves are 10cm apart and a spent match which is 40cm from one centre and 43cm from the other **does not** bob up and down at all. What is the largest possible wavelength for the waves in the puddle?

3 A stereo system is putting out a single note of wavelength 16cm and a microphone is placed in a position of destructive interference between its speakers. If the microphone is exactly 208cm from one speaker, what is its distance from the other speaker if the full stretch of its supply cable does not allow it to be further than 186cm.?

TUTORIAL 1 WAVES ANSWERS

1. The path difference between the two sources of waves and the boat is 40m. This is equivalent to 40/1.6 wavelengths. Since this is a whole number of wavelengths (25), there is constructive interference at the boat's mooring position.

2. The match must be in a place of destructive interference as the match is NOT bobbing up and down, hence the path difference (of 3 cm) must be equal to $\left(n+\frac{1}{2}\right)\lambda$.

Thus:

$$3=\left(n+\frac{1}{2}\right)\lambda$$
$$\therefore \lambda=\frac{3}{\left(n+\frac{1}{2}\right)}$$

The largest value of λ will occur for the smallest value of n, i.e. n = 0, thus $\lambda=\frac{3}{0.5}=6cm$

3.. Let the unknown distance be **d** cm. In order to get destructive interference, the path difference must be equal to $\left(n+\frac{1}{2}\right)\lambda$.

Thus

$$208-d=\left(n+\tfrac{1}{2}\right)\lambda$$
$$\Rightarrow \quad 208-d=\left(n+\tfrac{1}{2}\right)\times 16$$
$$\Rightarrow \quad d=208-\left(n+\tfrac{1}{2}\right)\times 16$$
$$=208-16\times n-8$$
$$=200-16n$$

The largest value of **d** which is not more than 186 cm occurs when **n=1**. This makes **d=184**. Thus the second speaker is 184 cm from the microphone.

3.

a) $T=\frac{1}{f}=\frac{1}{252\times10^{3}}=3.97\times10^{-6}\,s$

b) $\lambda=\frac{v}{f}=\frac{3\times10^{8}}{252\times10^{3}}=1190.5m$

4.

a) 0.546 μm.

b) 5.46 x 10^{-7} m

c)
$$f=\frac{v}{\lambda}=\frac{3\times10^{8}}{5.46\times10^{-7}}=5.49\times10^{14}\,Hz$$
$$T=\frac{1}{f}=\frac{1}{5.49\times10^{14}}=1.82\times10^{-15}\,s$$

TUTORIAL 2: WAVES

1. A grating with 200 lines per millimetre engraved on it gives an interference pattern where the second order maximum occurs at an angle of 11.5° to the zero order maximum. What is the wavelength of the light used?
2. A grating with a line spacing of 8x10^{-6}m is illuminated with light of wavelength 600nm. At what angle is the first order maximum found?
3. A maximum is found at an angle of 29.2°when light of wavelength 650nm is shone on a diffraction grating with a line spacing of 4x10^{-6}m What order maximum has been found?

TUTORIAL 2 ANSWERS

1.

$$d=\frac{1}{n}=\frac{1}{200\times10^{-3}}$$
$$or$$
$$d=\frac{\text{mm conversion to m}}{\text{no. of lines per mm}}$$

$$d\sin\theta=n\lambda \;\Rightarrow\; \frac{1\times10^{-3}}{200}\times\sin 11.5=2\times\lambda$$
$$\Rightarrow\; \lambda=4.984\times10^{-7}$$

The wavelength of this light is 498.4nm

2.

$$\begin{aligned} d\sin\theta = n\lambda \;\Rightarrow\;& 8\times10^{-6}\times\sin\theta = 1\times600\times10^{-9} \\ \Rightarrow\;& \sin\theta = 0.075 \\ \Rightarrow\;& \theta = 4.3^\circ \end{aligned}$$

The first order maximum is at an angle of 4.3^{o}.

3.

$$\begin{aligned} d\sin\theta = n\lambda \;\Rightarrow\;& 4\times10^{-6}\sin29.2 = n\times650\times10^{-9} \\ \Rightarrow\;& n = 3.002 \end{aligned}$$

We are looking at the third order maximum.

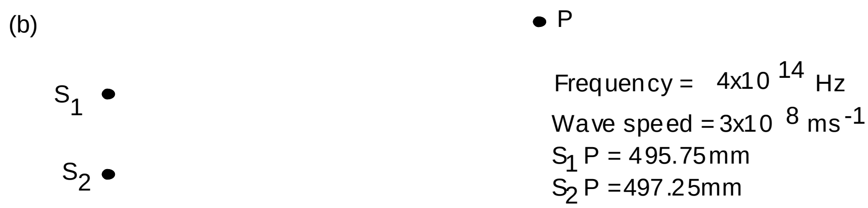
TUTORIAL 3

1. A flat piece of wood is dropped onto the surface of a pond in order to send out a set of waves. If the wood is released from a greater height, which of the following increases?

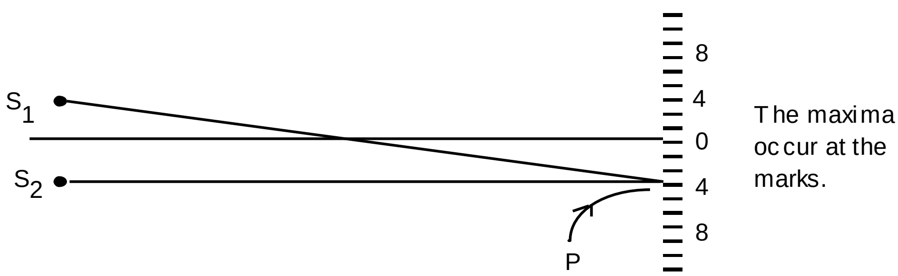
(a) Frequency, (b) Period, (c) Amplitude, (d) Speed, (e) Wavelength.

2. In each of the following examples, state whether the waves arriving at **P** are in or out of phase.

(a)

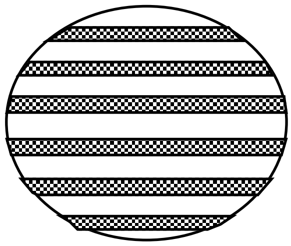


3.



If S_1P = 60cm and the wavelength in use is 1.2cm, what is the length of S_2P?

4. When a wire ring with a soap film across it is held horizontally in red light, we see that it has even bands of red and black across it as shown:



How do you think these interference bands are caused?

5. A line spectrum is formed using a diffraction grating with 100 lines per millimetre. On examination, it is suspected that one of the fuzzier lines might be two lines very close together. What change can we make that might resolve the problem?

6. At what angles do you find the red, green and blue lines of a spectrum using gratings with (a) 80 lines per mm, and (b) 300 lines per mm.?

TUTORIAL 3 ANSWERS

1. Dropping the wood from a greater height gives the waves more *energy* therefore their *amplitude* is increased.

2. (a) S_1P = 159.8cm and since the wavelength is 3.4cm, we have S_1P = 47 wavelengths.

Similarly S_2P = 47.5 wavelengths. Thus the *path difference* is half a wavelength so the two sets are exactly out of phase at P.

(b) The wavelength in use is given from

$$v = f\lambda \qquad \Rightarrow \qquad 3\times10^8 = 4\times10^{14}\times\lambda$$
$$\Rightarrow \qquad \lambda = 7.5\times10^{-7}$$

Thus S_1P = 495.75mm = 661000 wavelengths

S_2P = 497.25mm = 663000 wavelengths

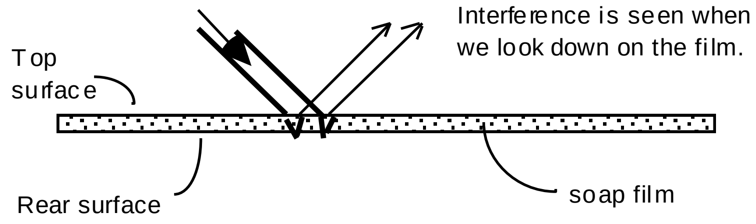
This makes the path difference 2000 wavelengths long so that both sets are in phase at P.

3.

Since the path difference is four wavelengths,

$$S_1P - S_2P = 4\times1.2\ cm$$
$$\Rightarrow \qquad S_2P = 60 - 4.8$$
$$= 55.2\ cm$$

4. The interference pattern is caused by light reflecting off the rear surface of the film interfering with the light reflecting off the top surface. The even spacing of the light and dark bands shows that the film is of uniform thickness.



5. Replace the grating with one containing more lines per millimetre, say 300lines/mm. This decrease in **d** spreads the spectrum more.
($\sin\theta = \dfrac{\lambda}{d}$ shows that a decrease in **d** gives a larger value of sinθ for each wavelength.)

6. Assuming you know the average wavelength of the colours are *red 740nm, green 530nm, blue 450nm* then,
(a) d = distance between adjacent slits
= 1mm/ 80
= $0.0125\text{x}10^{-3}$ m

$$\text{Red},\quad 740\times10^{-9} \quad \Rightarrow \quad \sin\theta = 0.0502$$
$$\Rightarrow \quad \theta = 3.4°$$
$$\text{Green}, 530\times10^{-9} \quad \Rightarrow \quad \sin\theta = 0.0423$$
$$\Rightarrow \quad \theta = 2.43°$$
$$\text{Blue},\quad 450\times10^{-9} \quad \Rightarrow \quad \sin\theta = 0.036$$
$$\Rightarrow \quad \theta = 2.06°$$

(b) d = $3.3\text{x}10^{-6}$m

$$\Rightarrow \quad \text{Red}, \theta = 12.83°$$
$$\Rightarrow \quad \text{Green}, \theta = 9.15°$$
$$\Rightarrow \quad \text{Blue}, \theta = 7.76°$$

TUTORIALS (SCET)

Waves

In an experiment to measure the period of a simple pendulum, the time for 20 complete swings was found to be 40 s.
Why were 20 swings timed?
What is the period of this pendulum?
What is the frequency of this pendulum?
A pupil counted 100 heartbeats during 60 swings of this pendulum. What is the period of his pulse?

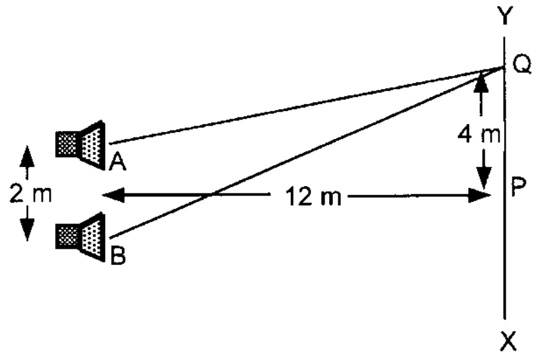
The ‘mains’ frequency is 50 Hz. How long does it take for one wave to be produced?

A ‘long wave’ radio station broadcasts on a frequency of 252 kHz.
What is the period of these waves?
What is the wavelength of these waves?

A green light has wavelength 546 nm.
Express this wavelength in micrometres (μm).
Express this wavelength in metres (using scientific notation).
Calculate the frequency and period of these light waves.

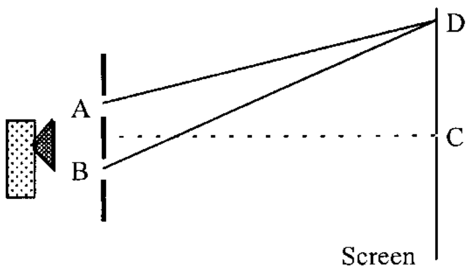
Explain how it is possible for interference to occur in the following situations:
a single loudspeaker emitting sound in a room with no other objects in the room
radio reception in a car when passing large buildings.

In an experiment on sound interference, two sources **A** and **B** are placed 2 m apart. As a girl walks from **X** to **Y** she hears a point of maximum loudness at point **P** and the next at point **Q**. Using information from the diagram below:
find distances **AQ** and **BQ**
calculate the wavelength of the sound
calculate the frequency of the sound
(speed of sound = 330 ms^{-1}).



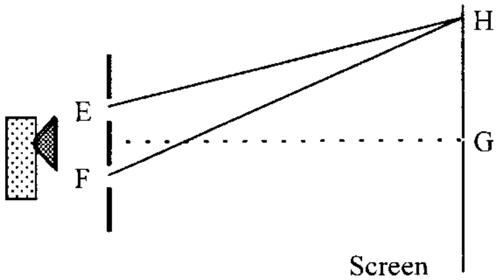
In the microwave experiment shown below, **C** is the zero order maximum and **D** is the first order maximum.
AD = 52 cm and **BD** = 55 cm.

What is the path difference at point **D**?
What is the wavelength of the microwaves?
What is the path difference to the second order maximum?
What is the path difference to the minimum next to C?
What is the path difference to the second order minimum?
What is the path difference at point **C**?



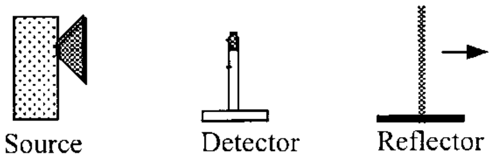
In a microwave interference experiment, **H** is the first **order** minimum, that is there is one other minimum between **H** and **G**. Measurement of distances **EH** and **FH** gives: **EH** = 42.1 cm and **FH** = 46.6 cm.

Calculate the wavelength and frequency of the microwaves used.



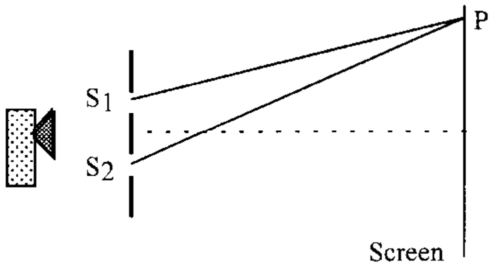
In a microwave experiment the waves reflected from a metal plate interfere with the incident waves on the detector. As the reflector is moved away from the detector, a series of maxima and minima are found.

A maximum is found when the reflector is at a distance of 25 cm from the detector and a further 8 maxima are found as the reflector is moved to a distance of
37.8 cm from the detector.



What is the average distance between maxima?
Calculate the wavelength of the microwaves.
Calculate the frequency of the microwaves.

In a microwave interference experiment, **P** is the **first** order minimum away from the centre. The measured distances and their uncertainties are:
$S_1P = 42.1 \pm 0.5$ cm $S_2P = 46.6 \pm 0.5$ cm



Calculate the wavelength of the microwaves and the uncertainty in this value of wavelength.

A grating with 600 lines per mm is used with a monochromatic source and gives the first order maximum at an angle of 20.5°.

Calculate the wavelength of the source.
What is the angle to the first order maximum if a grating of 1200 lines per mm was used?

Light of wavelength 600 nm is passed through a grating with 400000 lines per metre. Calculate the angle between the zero and first order maxima.

Light of wavelength 6.50×10^{-7} m is passed through a grating and the angle between the zero and third order maxima is 31.5°. Calculate the slit spacing of the grating.

Light of wavelength 500 nm is used with a grating of 500 lines/mm.

Calculate the angle between the first and second order maxima.

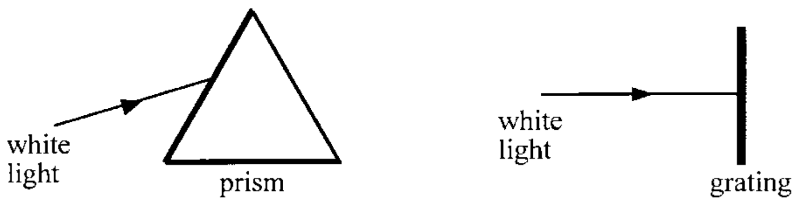
White light, with a range of wavelengths from 440 nm to 730 nm is passed through a grating with 500 lines/mm.

Describe what would be seen.
Explain the pattern produced.
Calculate the angle between the extremes of the first order maximum, i.e. the angle between violet and red.

A green filter is placed in front of a white light source and the filtered light is passed through a grating with 300 lines/mm. A pattern of bright and dark bands is produced on a screen.

What colour are the bright bands of light?
Explain whether the spacing of the bright bands would increase or decrease when the following changes were made:
using a blue filter instead of a green filter
using a grating with 600 lines/mm
using a brighter lamp
bringing the screen closer to the grating.

Spectra can be produced from white light by two methods as shown below.



Copy and complete the above diagrams to show the spectra produced.
List the differences between the two spectra produced.

ANSWERS:
TUTORIAL 1
1. There is constructive interference at the boat's mooring position.
2. Maximum wavelength is 6cm.
3. The second speaker is 184cm from the microphone.

TUTORIAL 2
1. The wavelength of this light is 498.4nm
2. The first order maximum is at an angle of 4.3^{o}.
3. We are looking at the third order maximum

TUTORIAL 3
1. Dropping the wood from a greater height gives the waves more energy therefore their amplitude is increased.

2. (a) The two sets are exactly out of phase at P.
   (b) Both sets are in phase at P.
3. $S_2P = 55.2$cm
4. The interference pattern is caused by light reflecting off the rear surface of the film interfering with the light reflecting off the top surface. The even spacing of the light and dark bands shows that the film is of uniform thickness.
5. Replace the grating with one containing more lines per millimetre.
6. Assuming you know the average wavelength of the colours are red 740nm, green 530nm, blue 450nm then,

Red $\theta = 3.4^\circ$

Green $\theta = 2.43^\circ$

Blue $\theta = 2.06^\circ$

Red $\theta = 12.83^\circ$

Green $\theta = 9.15^\circ$

Blue $\theta = 7.766^\circ$

Waves

b) 2s c) 0.5 Hz d) 1.2 s.

0.02 s.

a) 3.97×10^{-6} s b) 1190.5 m.

a) 0.546 μm b) 5.46×10^{-7} m c) 5.49×10^{14} Hz, 1.82×10^{-15} s.

a) AQ = 12.37 m, BQ = 13.00 m b) 0.63 m c) 524 Hz.

a) 3 cm b) 3 cmc) 6 cm d) 1.5 cm e) 7.5 cm f) zero.

3cm, 1.0×10^{10} Hz.

a) 1.6 cm b) 3.2 cm c) 9.38×10^{9} Hz.

3.0 ± 0.04 cm.

a) 5.84×10^{-7} m b) 44.5°.

13.9°.

3.73×10^{-6} m.

15.5°.

a) A repeating continuous spectrum (from violet to red) would be produced either side of the centre line of the diffraction grating. The light at the centre line would be white.

b) For a given value of n, the value of dsinθ is smaller for smaller wavelengths, therefore q is also smaller for smaller wavelengths. As wavelength increases so does the angle for the nth order constructive interference points

c) 8.7°.

16. a) The bright bands are green.

b) i) Blue light has a shorter wavelength than green, therefore nl is smaller and hence q is smaller. Therefore the bands will be closer together.

ii) Halving d will require sinq to double for the same value of nl. Therefore q will be larger and the bands will be further apart.

iii) A brighter lamp will have no effect on the spacing since the wavelength is not affected.

iv) q will remain the same so the bands will move closer together.

17.

$$n = \frac{\sin i}{\sin r}$$

$$i = 90 - 43 = 47°$$

$$r = 90 - 61 = 29°$$

$$n = \frac{\sin 47}{\sin 29} = \frac{0.731}{0.485} = 1.51$$

The bright fringes occur as a result of constructive interference between rays of light which have traveled different distances to get to the same point. Constructive interference occurs when the path difference is a whole number of wavelengths.

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

$$d = \frac{1}{300\times10^{3}} = 3.33\times10^{-6}\ m$$

$$n = 2, \qquad \lambda = 650\times10^{-9}\ m$$

$$3.33\times10^{-6}\sin\theta = 2\times650\times10^{-9}$$

$$\sin\theta = \frac{2\times650\times10^{-9}}{3.33\times10^{-6}} = 0.390$$

$$\theta = 23.0^\circ$$

The spacing between the bright fringes will become closer together. Blue light has a shorter wavelength than red light and as λ decreases, so does $n\lambda$ and therefore $\sin\theta$ and hence θ must also decrease. Therefore the dots move closer together.

CHAPTER 8 REFRACTION OF LIGHT

REFRACTION /TUTORIAL 1

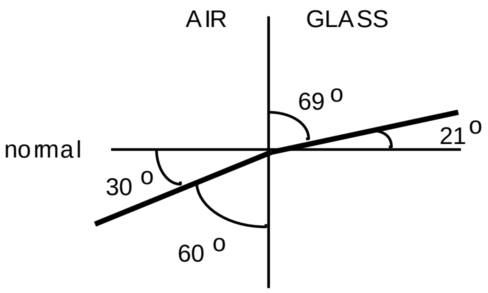
1. Light travelling at $3x10^8$ m s^{-1} strikes the surface of a glass block at 50^o to the normal. If its velocity inside the block is $2x10^8$ m s^{-1}, at what angle to the normal is it travelling there?

2. Light of wavelength 500 nm and velocity $3x10^8$ m s^{-1} is incident on the end of a fibre optic cable inside which its velocity is $1.9x10^8$ m s^{-1}. What is the wavelength of this light inside the cable?

3. As light crosses a boundary between two media, its wavelength changes from 600 nm to 450 nm. If the angle between the light and the normal is 30^o inside the second medium, what is its angle of incidence on it?

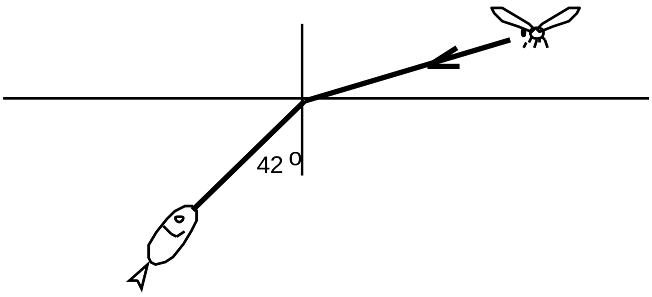
REFRACTION /TUTORIAL 2

1. What is the refractive index of the glass in this diagram?



2. A perspex block of refractive index 1.2 has light striking it at 40^o to the normal. What is the angle between the light and the normal inside the block?

3. A fish sees a fly a few centimetres above the level water surface of a tank.



If the refractive index of the water is 1.29, at what angle is the light from the fly actually striking the water?

DISCUSSION OPPORTUNITY: Looking at this situation from the fish's point of view, what is wrong with making a grab for this fly directly at where it appears to be?

REFRACTION /TUTORIAL 3

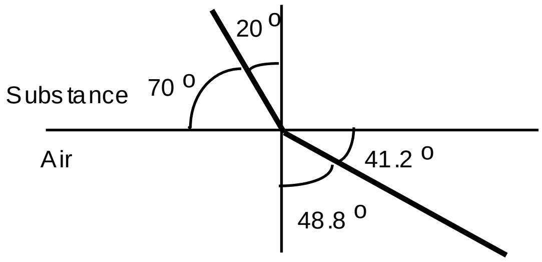
1. What is the critical angle of a glass whose refractive index is 1.4?

2. What is the refractive index of a plastic material whose critical angle is 41.81^{o}?

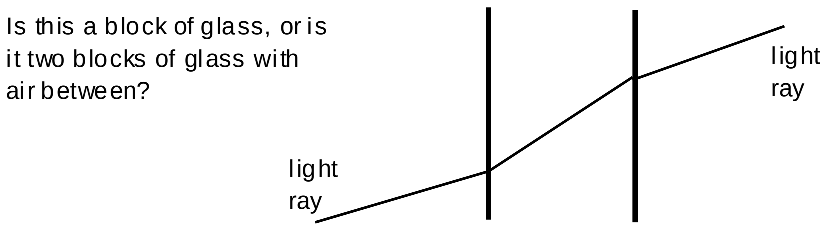
3. If the refractive index of a precious stone is 1.9 and that of a dense glass is 1.7, which has the smaller critical angle?

REFRACTION /TUTORIAL 4

1. What is the refractive index of the substance shown in this diagram?



2.

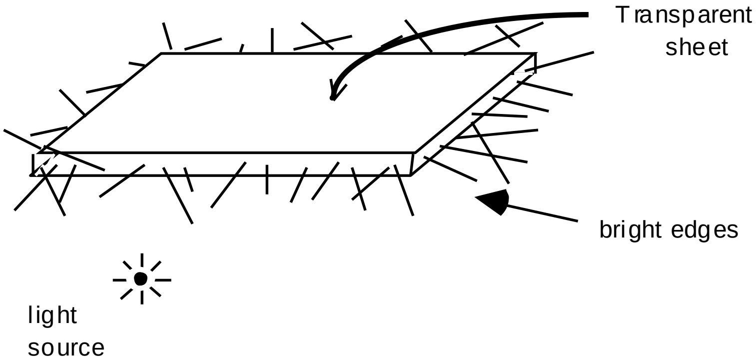


3. Green light of wavelength 535 nm travelling down a glass vacuum tube is incident at 80^{o} with one wall. If its angle of refraction inside the glass is 44.7^{o},

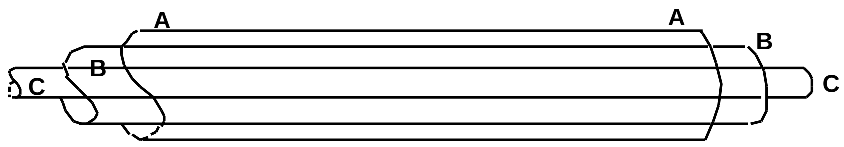
   (a) At what speed is it moving through the glass?

   (b) What is its wavelength in the glass?

4. We can obtain plastic sheet that appears transparent but which becomes bright round its *edges* if we shine a light on it. Explain how this happens.



5. This is a cross-section of an optical fibre:-



The materials used are:-

POLY METHYL METHACRYLATE of refractive index 1.59

POLYTHENE which is opaque

FLUORINATED POLYMER of refractive index 1.35

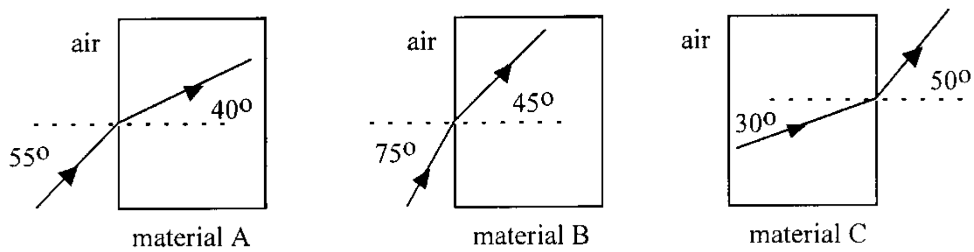
What letter is used for each of these materials in the diagram above?

6. (a) What is the critical angle for a transparent plastic with a refractive index of 1.59?

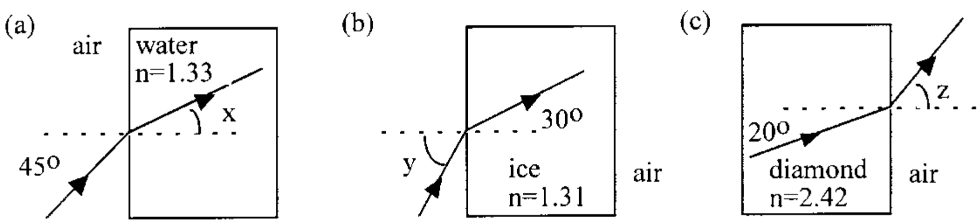
   (b) A similar plastic has a critical angle of 48°. Does is have a higher or lower refractive index?

TUTORIALS (SCET) Refraction of light

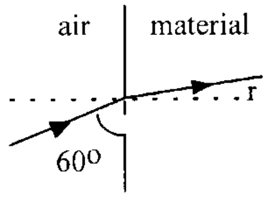
10. Calculate the refractive index *n* of each of the materials below:



11. Calculate the missing angle in each of the following diagrams:

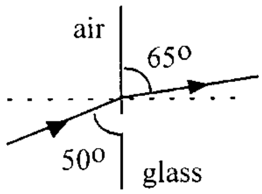


12. The refractive index of the material shown in the diagram below is 1.35.



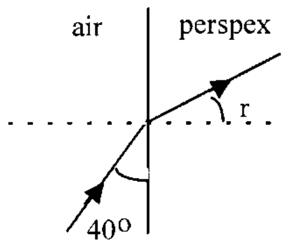
a) Calculate the angle *r*.
b) Find the velocity of the light in the material.

13. A ray of light of wavelength 6.00×10^{-7} m passes from air to glass as shown below.



a) Calculate the refractive index of the glass.
b) Calculate the speed of light in the glass.
c) Calculate the wavelength of the light in the glass.
d) Calculate the frequency of the light in air.
e) State the frequency of the light in the glass.

14. A ray of light of wavelength 500 nm passes from air into perspex of refractive index 1.50 as shown.

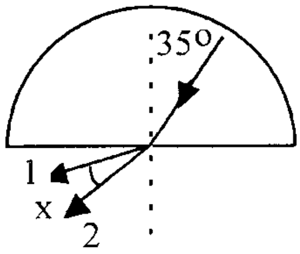


a) Calculate the angle *r*.
b) Calculate the speed of light in the perspex.
c) Calculate the wavelength of light in perspex.

15. The refractive index for red light in crown glass is 1.513 and for violet light it is 1.532.

a) Using this information, explain why white light can produce a spectrum when passed through crown glass.

16. A ray of white light passes through a semi-circular block of crown glass as shown and produces a spectrum.

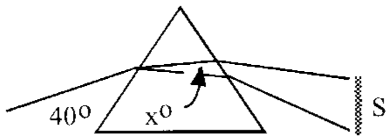


a) Which exit ray is red and which ray is violet?
b) Calculate the refracted angle in air for each of the exit rays.
c) Find angle *x,* the angle between the red and violet rays.

17. A ray of white light is dispersed by a prism producing a spectrum, S.

The angle $x°$ between red light and blue light is found to be 0.7°.

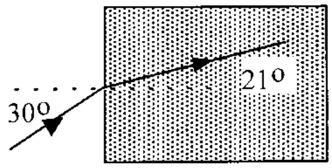
If the refractive index for red light is 1.51, calculate the refractive index for blue light.



18. Calculate the critical angle for each material using the refractive index given in the table below.

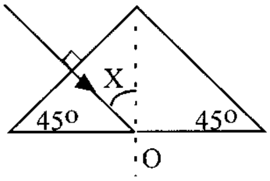
MATERIAL	N
Glass	1.54
Ice	1.31
Perspex	1.50

19. A beam of infrared radiation is refracted by a type of glass as shown.



a) Calculate the refractive index of the glass for infrared.
b) Calculate the critical angle of the glass for infrared.

20. A ray of light enters a glass prism of absolute refractive index 1.52, as shown:



a) Why does the ray not bend on entering the glass prism?
b) What is the value of angle **X**?
c) Why does the ray undergo total internal reflection at **O**?
d) Redraw the complete diagram showing the angles at **O** with their values.
e) Explain what would happen if the experiment was repeated with a prism of material with refractive index of 1.30.

The absolute refractive indices of water and diamond are 1.33 and 2.42 respectively.

a) Calculate the critical angles for light travelling from each substance to air.
b) Comment on the effect of the small critical angle of diamond on the beauty of a well cut stone.

ANSWERS:

TUTORIAL 1

1. It travels at 30.7^{o} to the normal inside the glass block.

2. The wavelength inside the cable is 317nm

3. The angle of incidence is 41.8^{o}

TUTORIAL 2

1. The refractive index of the glass is 1.4

2. The angle of refraction is 32.4^{o}

3. The light from the fly makes an angle of incidence of approximately 60^{o} with the water surface.

TUTORIAL 3

1. The critical angle is 45.6^{o}.

2. The refractive index is 1.5

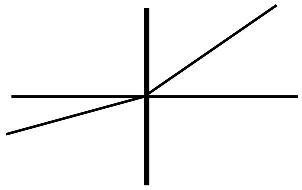
3. The lower the refractive index, the larger the angle before total internal reflection occurs. This explains why precious stones, which have high refractive indices, are so sparkly. They reflect more light internally.

TUTORIAL 4

1. Refractive index 2.2

2.

The left hand boundary by itself:-



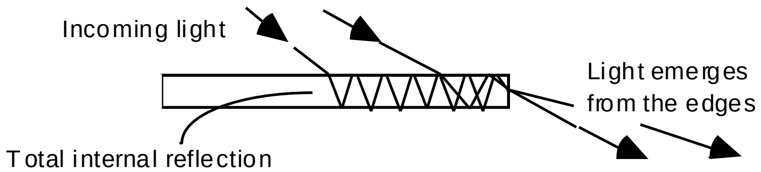
The right hand side ray is further from the normal than the ray on the left. Thus the left hand side of this boundary has a greater refractive index than the right and so the gap is air.

3.

(a) speed in glass = 2.14×10^{8} ms^{-1}

(b) Using the wavelength version of the above equation gives the wavelength in glass as 382nm

4. The plastic causes a large fraction of the light to be reflected internally so that it emerges from the edges:-



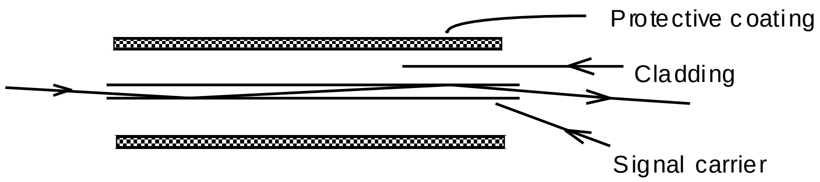
5. A ----- Polythene

B ----- Fluorinated polymer

C ----- Polymethylmethacrylate

The outer coating is protection against mechanical hazards like scrapes and scratches.

The central core is *highly* transparent and carries the signal while the **B** layer is a cladding of lower refractive index than the core so that total internal reflection occurs at the boundary.



6. (a) The critical angle is 38.9^{o}.

(b) Using the same equation as above gives the refractive index of the second type of plastic as 1.35, which is lower than the first.

TUTORIALS (SCET)
REFRACTION OF LIGHT

1. nA = 1.27, nB = 1.37, nC = 1.53.
2. a) 32.1° b) 40.9° c) 55.9°.
3. a) 21.7° b) 2.22×10^{8} ms^{-1}.
4. a) 1.52 b) 1.97×10^{8} ms^{-1} c) 3.95×10^{-7} m d), e) 5.00×10^{14} Hz.
5. 30.7° b) 2.00×10^{8} ms^{-1} c) 333 nm.
6. c) Red = 60.2°, Violet = 61.5° d) 1.3°.
7. 1.54.

8. Glass 40.5°, Ice 49.8°, Perspex 41.8°.
9. a) 1.40 b) 45.6°.
10. b) 45°.
11. a) Water 48.8°, Diamond 24.4°.

TUTORIALS (SCET)

1.

$$n = \frac{\sin\theta_1}{\sin\theta_2}$$

$$A: \quad n = \frac{\sin 55}{\sin 40} = 1.27$$

$$B: \quad n = \frac{\sin 75}{\sin 45} = 1.37$$

$$C: \quad n = \frac{\sin 50}{\sin 30} = 1.53$$

2.

a)

$$\sin\theta_2 = \frac{\sin\theta_1}{n}$$

$$\sin\theta_2 = \frac{\sin 45}{1.33} = 0.532$$

$$x = \theta_2 = 32.1°$$

$$\sin\theta_1 = n\sin\theta_2$$

$$\sin\theta_1 = 1.31 \times \sin 30 = 0.655$$

$$y = \theta_1 = 40.9°$$

b)

$$\sin\theta_1 = n\sin\theta_2$$

$$\sin\theta_1 = 2.42 \times \sin 20 = 0.828$$

$$z = \theta_1 = 55.9°$$

3.

a)

$$\sin\theta_2 = \frac{\sin\theta_1}{n}$$

$$\sin\theta_2 = \frac{\sin(90-60)}{1.35} = 0.370$$

$$r = \theta_2 = 21.7°$$

b)

$$\frac{v_1}{v_2} = \frac{\sin\theta_1}{\sin\theta_2}$$

$$\frac{3\times10^8}{v_2} = \frac{\sin 30}{\sin 21.7} = 1.352$$

$$v_2 = \frac{3\times10^8}{1.352} = 2.22\times10^8\, m\, s^{-1}$$

4.

a)

$$n = \frac{\sin\theta_1}{\sin\theta_2}$$

$$n = \frac{\sin(90-50)}{\sin(90-65)} = 1.52$$

b)

$$\frac{v_1}{v_2} = \frac{\sin\theta_1}{\sin\theta_2}$$

$$\frac{3\times10^8}{v_2} = \frac{\sin 40}{\sin 25} = 1.52$$

$$v_2 = \frac{3\times10^8}{1.52} = 1.97\times10^8\, m\, s^{-1}$$

c)

$$\frac{\lambda_1}{\lambda_2} = \frac{\sin\theta_1}{\sin\theta_2}$$

$$\frac{6.00\times10^{-7}}{\lambda_2} = \frac{\sin 40}{\sin 25} = 1.52$$

$$\lambda_2 = \frac{6.00\times10^{-7}}{1.52} = 3.95\times10^{-7}\, m$$

$$f = \frac{v}{\lambda}$$

$$f = \frac{3\times10^8}{6.00\times10^{-7}} = 5\times10^{14}\, Hz$$

d)

e) $$f = \frac{v}{\lambda}$$

$$f = \frac{1.97\times10^{8}}{3.95\times10^{-7}} = 5\times10^{14}\,Hz$$

5.

a) $$\sin\theta_2 = \frac{\sin\theta_1}{n}$$

$$\sin\theta_2 = \frac{\sin(90-40)}{1.50} = 0.511$$

$$r = \theta_2 = 30.7^\circ$$

b) $$\frac{v_1}{v_2} = \frac{\sin\theta_1}{\sin\theta_2} = n$$

$$\frac{3\times10^{8}}{v_2} = 1.50$$

$$v_2 = \frac{3\times10^{8}}{1.50} = 2.00\times10^{8}\,m\,s^{-1}$$

c) $$\frac{\lambda_1}{\lambda_2} = \frac{\sin\theta_1}{\sin\theta_2} = n$$

$$\frac{500\times10^{-9}}{\lambda_2} = 1.50$$

$$\lambda_2 = \frac{500\times10^{-9}}{1.50} = 333\,nm$$

6.

a) For a given value of θ_1 the value of θ_2 for red and violet light will be different because their refractive indices are different (according to

$\sin\theta_2 = \frac{\sin\theta_1}{n}$). Thus the two colours (indeed all the intermediate colours) will be refracted through slightly different angles and the white light will therefore be split into a spectrum.

b) The value of n is smaller for red light, therefore sin θ_1 and hence θ_1 will be smaller for red light. Thus red light is refracted through a smaller angle than violet. Therefore ray 1 is violet and ray 2 is red.

c)
$$\sin\theta_{red} = n\sin\theta_2$$
$$\sin\theta_{red} = 1.513 \times \sin 35 = 0.868$$
$$\theta_{red} = 60.2°$$

$$\sin\theta_{violet} = n\sin\theta_2$$
$$\sin\theta_{violet} = 1.532 \times \sin 35 = 0.879$$
$$\theta_{violet} = 61.5°$$

d)
$$x = \theta_{violet} - \theta_{red} = 61.5 - 60.2$$
$$x = 1.3°$$

7.
$$\sin\theta_{red} = \frac{\sin\theta_1}{n_{red}}$$
$$\sin\theta_{red} = \frac{\sin(90-40)}{1.51} = 0.507$$
$$\theta_{red} = 30.5°$$
$$\theta_{red} - \theta_{blue} = 0.7° \quad \text{(going into the glass so red is refracted most)}$$
$$\theta_{blue} = 30.5 - 0.7 = 29.8°$$
$$n_{blue} = \frac{\sin(90-40)}{\sin 29.8} = 1.54$$
$$\sin\theta_C = \frac{1}{n}$$
$$\sin\theta_{glass} = \frac{1}{1.54} = 0.649$$
$$\theta_{glass} = 40.5°$$
$$\sin\theta_{ice} = \frac{1}{1.31} = 0.763$$
$$\theta_{ice} = 49.8°$$
$$\sin\theta_{perspex} = \frac{1}{1.50} = 0.666$$
$$\theta_{perspex} = 41.8°$$

8.

a)

$$n = \frac{\sin\theta_1}{\sin\theta_2}$$

$$n = \frac{\sin 30}{\sin 21} = 1.40$$

b)

$$\sin\theta_C = \frac{1}{n}$$

$$\sin\theta_{glass} = \frac{1}{1.40} = 0.714$$

$$\theta_{glass} = 45.6°$$

9.

a) The ray is entering the prism perpendicular to the surface.

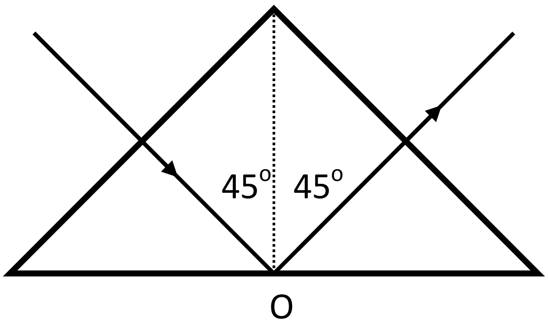
b) 45^o

c)

$$\sin\theta_C = \frac{1}{n} = \frac{1}{1.52} = 0.658$$

$$\theta_C = 41.1°$$

The angle of incidence (45^o) is greater than the critical angle so the ray undergoes total internal reflection.



d)

$$\sin\theta_C = \frac{1}{n} = \frac{1}{1.30} = 0.769$$
$$\theta_C = 50.3°$$

The angle of incidence would be less than the critical angle so the ray would emerge from the prism at point O and undergo refraction.

10.

a)

$$\sin\theta_{water} = \frac{1}{n} = \frac{1}{1.33} = 0.752$$
$$\theta_{water} = 48.8°$$
$$\sin\theta_{diamond} = \frac{1}{n} = \frac{1}{2.42} = 0.413$$
$$\theta_{diamond} = 24.4°$$

CHAPTER 9 SPECTRA