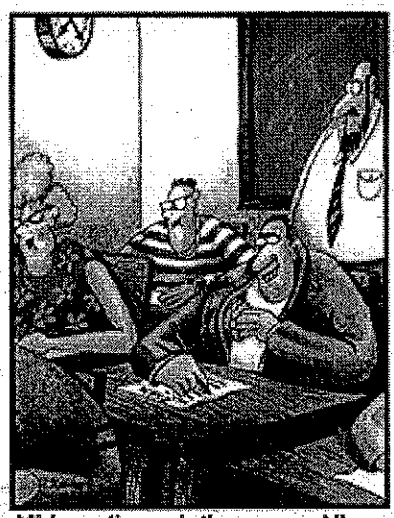
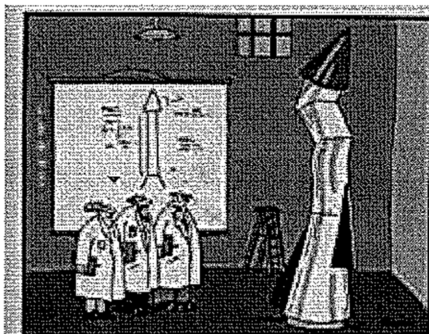
Physics 30

Diploma Review



Midway through the exam, Allen pulls out a bigger brain.

From Gary Larson, the Far Side



"It's time we face reality, my friends, ... We're not exactly rocket scientists."

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Physics 30 Diploma Exam – What to Expect

The design of the Physics 30 Diploma Examination is as follows:

When?	Format	# of Questions	Percentage
9:00 – 11:00 (plus 30 minutes)	Multiple Choice Numerical Response	36 14	72% 28%

Multiple-choice questions are of two types: **discrete** and **context-dependent**.

A **discrete** question stands on its own without any additional directions or information. It may take the form of a question or an incomplete statement.

A **context-dependent** question provides information that is separate from the question stem. Many of the multiple-choice questions are context dependent. A particular context may be used for more than one multiple-choice question as well as for more than one numerical-response question.

Numerical-response questions are of three types:

1. calculation of numerical values.
2. selection of numbered events, structures, or functions from a diagram/list.
3. determination of a sequence of events.
4. selection of physics principles required to solve a problem
   —uniform motion (balanced forces)
   —uniformly accelerated motion (unbalanced forces)
   —circular motion (unbalanced forces)
   —conservation of momentum
   —conservation of energy
   —conservation of mass-energy
   —conservation of charge
   —conservation of nucleons
   —wave-particle duality

Note: **Many students experience difficulty recording their answers to numerical-response questions. These difficulties include failing to completely fill in the circles on the answer sheet, failing to fill in the circles that correspond to the digits recorded in the boxes, and incorrect rounding.**

I strongly recommend that students check out the following links:

1. The **Physics 20/30 Program of Studies** is the curriculum that students will be tested on.
   http://education.alberta.ca/media/654853/phy2030_07.pdf

2. The **Physics 30 2010–2011 Bulletin** provides sample questions and answers.
   http://www.education.alberta.ca/admin/testing/diplomaexams/exambulletins.aspx

UNIT I – MOMENTUM (10 – 20%)

Impulse and Change in Momentum

Momentum is a vector quantity which is defined as the product of a body's mass and its velocity.

$$\vec{p} = m\vec{v}$$

A **change in momentum** is due to a change in velocity → speed + direction

$$\Delta\vec{p} = m\Delta\vec{v} \qquad \text{kg·m/s}$$

A change in momentum is the result of a force acting over a time which is called **impulse**

$$\vec{J} = \vec{F}\Delta t \qquad \text{N·s}$$

↓ force over a time

Impulse is equivalent to the **change in momentum**.

$$\vec{F}\Delta t = m\Delta\vec{v} \qquad \text{N·s = kg·m/s}$$

Diploma exam alert:

- ⇒ **Impulse is force × time**. Do not confuse force with impulse.
- ⇒ Safety questions. A change in momentum can be the result of a large force over a short time or a smaller force over a longer period of time – i.e. crumple zones on cars, bungee cords, ropes that stretch.
- ⇒ F vs t graphs. The impulse or change in momentum = the **area of a force–time graph.**
- ⇒ Impulse results in a **change** in velocity. **Do not confuse** $\Delta\vec{v}$ **with** $\vec{v}_{final}$. $\Delta\vec{v} = \vec{v}_{final} - \vec{v}_{initial}$

Numerical Response

1. An 8.00 kg infant is in a 16.4 kg baby carriage being pushed along at a speed of 3.50 m/s. The child's father applies an extra force of 3.65 N forward on the carriage for 3.40 s. The final speed of the carriage, recorded with three digits, is ***a.bc*** m/s. The values of ***a***, ***b***, and ***c*** are ____, ____, and ____.

(Record all **three digits** of your answer in the numerical-response section on the answer sheet.)

impulse = Δp
(father) = (carriage)
$F\Delta t = m(v_f - v_i)$
$(3.65)(3.40) = 24.4(v_f - 3.50)$
$12.41 = 24.4(v_f - 3.50)$
$0.500 = v_f - 3.50$
$4.01\ \text{m/s} = v_f$

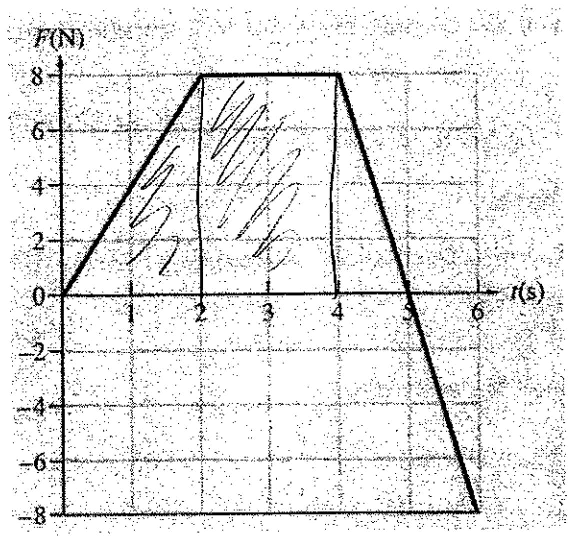
1. The SI units for impulse may be written as

A. $kg{\cdot}m/s^2$
B. $kg{\cdot}m^2/s^2$
C. $kg{\cdot}m^2/s$
(D.) $kg{\cdot}m/s$

$F\Delta t = m\Delta v$
$N{\cdot}s = kg{\cdot}m/s$

Use the following information to answer the next question.

Force on a Ball as a Function of Time



2. The net impulse delivered to the ball from t = 0.0 s to t = 4.0 s is

Ⓐ 24 N·s
B. 28 N·s
C. 32 N·s
D. 48 N·s

area = impulse
△ + □ = impulse
$\frac{1}{2}bh + lw$ = impulse
$\frac{1}{2}(2 \cdot 8) + (2 \cdot 8)$ = impulse
8 + 16 = impulse
24 N·s = impulse

3. A rock climber falls and is saved from injuries by a climbing rope that is slightly elastic. The importance of the elasticity of the climbing rope can be understood in terms of impulse because elasticity results in

Ⓐ decreased force during an increased time interval
B. increased force during an increased time interval
C. decreased force during a decreased time interval
D. increased force during a decreased time interval

impulse = Δp
Ft = Δp

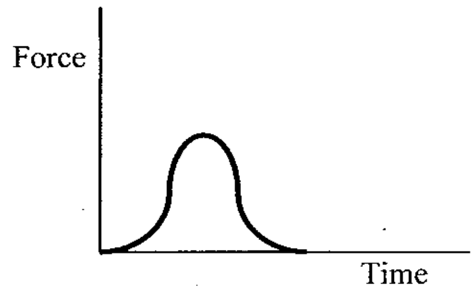
4. A tennis ball with a mass of 110 g is travelling 18.5 m/s east. It is struck by a racquet that applies a force of 950 N west. The ball and the racquet are in contact for 3.20 ms. The change in momentum of the tennis ball is

A. 2.04 kg·m/s, west
Ⓑ 3.04 kg·m/s, west
C. 2.04×10^3 kg·m/s, west
D. 3.04×10^3 kg·m/s, west

impulse = Δp
$F \Delta t = \Delta p$
$950 \cdot 3.2 \times 10^{-3} = \Delta p$
3.04 N·s = Δp [W]

Use the following information to answer the next question.

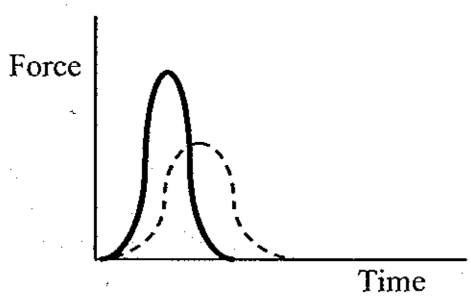
A particular experimental apparatus is designed to analyze the concept of impulse. The apparatus consists of a force plate that is attached to a computer. The plate is made of steel. When a steel ball is allowed to fall from a height on to the force plate, the resulting force–time graph is:



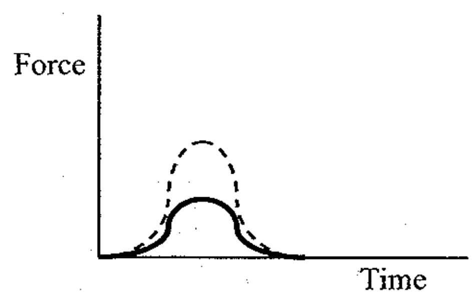
The experimenter then places a one centimeter thick piece of foam rubber over the force plate to act as a cushion. Another steel ball is dropped from the same height as before onto the cushioned force plate.

5. Which of the following would be the resulting cushioned force–time graph?

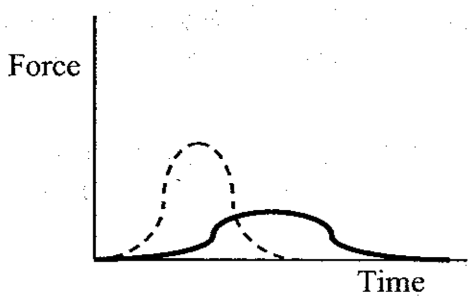
A.



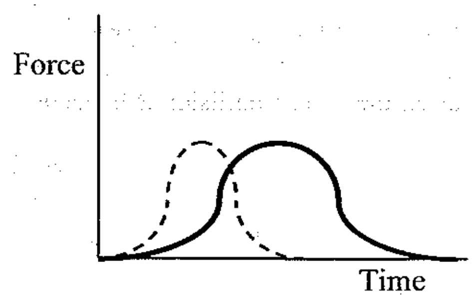
B.



C.



D.



↓force ↑time

Ft

Conservation of Momentum

The **Law of Conservation of Momentum** states that the **total momentum of an isolated system is conserved** (constant). An **isolated system** is one where there the sum of the external forces acting on the system is zero.

$$\Sigma\vec{p}_{\text{initial}} = \Sigma\vec{p}_{\text{final}} \qquad \text{or} \qquad \Sigma\vec{p} = \Sigma\vec{p}'$$

The total momentum of the system in the initial situation equals the total momentum of the system in the final situation. There are two basic interactions – **collision** problems and **recoil/explosion** problems.

For **collisions** there are two basic situations – either objects will **bounce** off each other or they **stick** together on impact.

$$\Sigma\vec{p} = \Sigma\vec{p}'$$

$$m_1\vec{v}_1 + m_2\vec{v}_2 = m_1\vec{v}_1' + m_2\vec{v}_2'$$

→ Ek not conserved.

Momentum always conserved

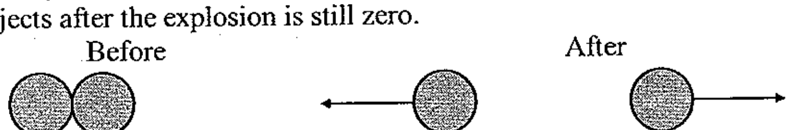
$$\Sigma\vec{p} = \Sigma\vec{p}'$$

$$m_1\vec{v}_1 + m_2\vec{v}_2 = (m_1 + m_2)\vec{v}'$$

Elastic collisions are those where **both momentum and kinetic energy** are conserved. Purely elastic collisions are very hard to produce in the ordinary world because there is always some kinetic energy converted into heat, sound, deformation or some other form of energy. Elastic collisions occur for collisions between subatomic particles.

Inelastic collisions are those where **momentum is conserved, but kinetic energy is not conserved**. The objects may bounce off of each other or they may couple or stick together after impact. Unless you are told otherwise, assume that a collision is inelastic.

Recoil/explosion problems involve situations where the initial momentum is zero and the objects explode or move away from each other. Since the momentum of the system is conserved, the sum of the momenta of the objects after the explosion is still zero.



$$\Sigma\vec{p} = \Sigma\vec{p}'$$

Explosion $$0 = m_1\vec{v}_1' + m_2\vec{v}_2'$$

Diploma exam alert:

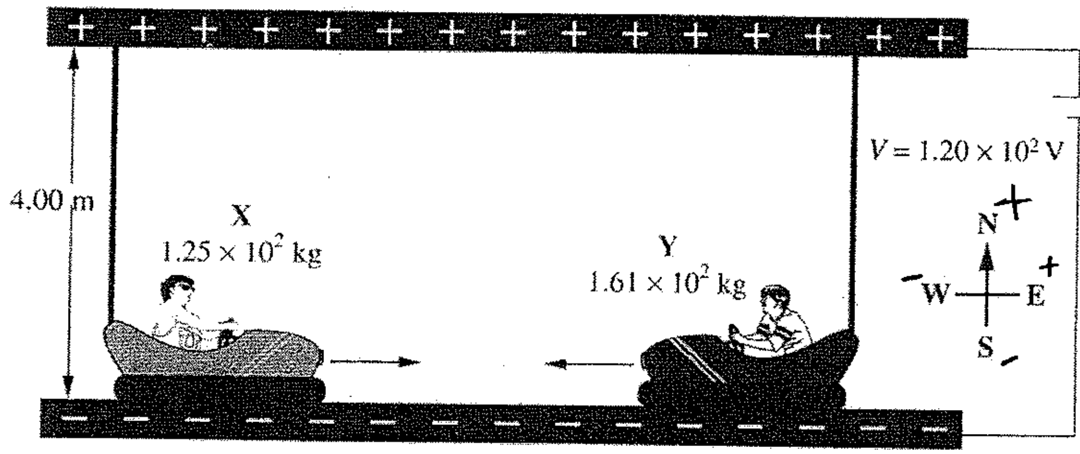
- ⇒ **Momentum is always conserved.** Kinetic energy can be "lost" as heat.
- ⇒ Momentum is a **vector** and energy is a **scalar**.

6. The following statements all relate to a collision between any two objects on a horizontal frictionless surface. Which of these statements is always true?

lost as heat

A. The kinetic energy of each object before and after the collision is the same.
B. The momentum of each object before and after the collision is the same.
(C.) The total momentum of the two objects before and after the collision is the same.
D. With respect to the surface, the gravitational potential energy of each object before and after the collision increases.

Use the following information to answer the next question.



Bumper cars operate on electricity. The more the accelerator pedal is pressed, the more current flows in the system, thus the faster the car travels. Car **X** and car **Y** are going to collide head-on. Car **X** is travelling at a constant velocity of 2.25 m/s to the east and car **Y** is travelling at a constant velocity of 1.30 m/s to the west.

7. If after the collision car Y is travelling at 0.526 m/s to the east, the velocity of car X immediately after impact would be

(A.) 1.02×10^{-1} m/s to the west
B. 3.25 m/s to the east
C. 4.60 m/s to the east
D. 1.02×10^{1} m/s to the west

elastic 1D (don't stick)

$p_b = p_a$

$m_a v_a + m_b v_b = m_a v_a' + m_b v_b'$

$1.25e^2 \cdot 2.25 + 1.61\times10^2 \cdot -1.3 = 1.25e^2(v_A') + 1.61e^2(.526)$

$281.25 + -209.3 = 125 v_A' + 84.686$

$71.95 - 84.686 = 125 v_A'$

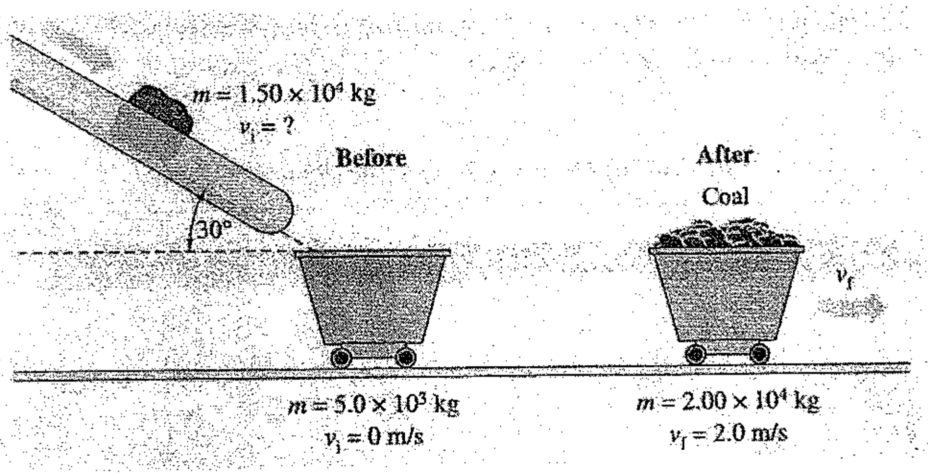
$\frac{-12.736}{125} = v_A'$

-0.102 m/s $= v_A'$ (west)

Dr. Ron Licht

Use the following information to answer the next question.

A coal chute angled at 30° to the horizontal releases 1.50×10^4 kg of coal to fill a stationary, empty 5.0×10^3 kg cart. The cart and coal move forward with a horizontal velocity of 2.0 m/s.



8. The speed of the coal along the chute is

A. 1.5 m/s

B. 2.7 m/s

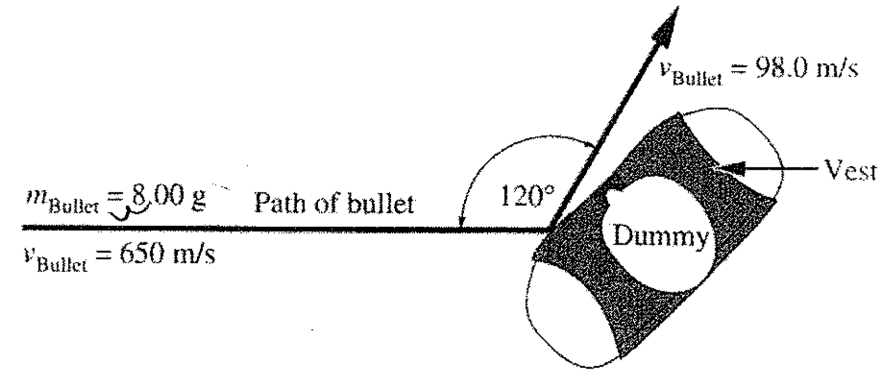
C. 3.1 m/s

D. 5.3 m/s

The Law of Conservation of Momentum also applies to **two dimensional interactions**. Since momentum is a vector quantity that is conserved during interactions, we use either **components** or **the cosine law** to solve two dimensional problems.

Use the following information to answer the next question.

A test performed by a company has a bullet strike a bullet-proof vest at a glancing angle. The mass of the vest and the dummy is 56.0 kg. The bullet-vest collision is inelastic.



Example problem – Component method

The resultant velocity of the vest and the dummy following the glancing collision shown above, expressed in scientific notation, is $\boldsymbol{a.bc} \times 10^{-d}$ m/s at $\boldsymbol{e.fg}$ ° below the original path of the bullet. The values of $\boldsymbol{a}$, $\boldsymbol{b}$, $\boldsymbol{c}$, $\boldsymbol{d}$, $\boldsymbol{e}$, $\boldsymbol{f}$, and $\boldsymbol{g}$ are ____, ____, ____, ____, ____, ____, and ____.

$m_a v_a + 0 =$

$(0.008\text{kg} \cdot 650) = 5.2$

Py [sin 60 = x/98]

x = .679

4.08/58

.679/58

Px .608 [cos 60 = x/98]

=

Px = Px

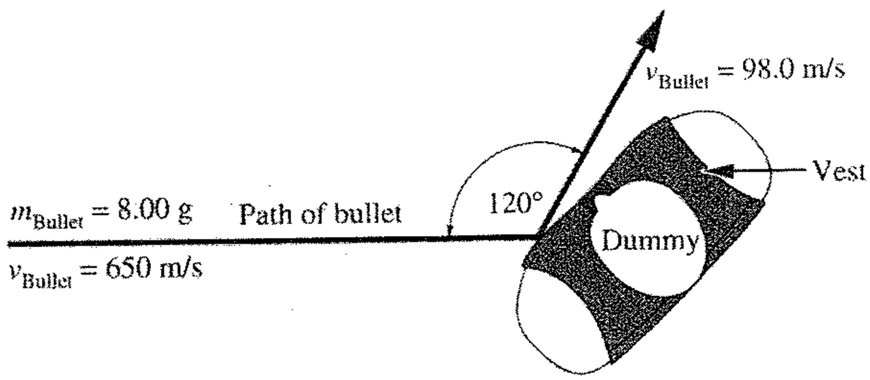
5.2 = .392 + x

= 4.08

8.17×10⁻² 8.03° 58

Use the following information to answer the next question.

A test performed by a company has a bullet strike a bullet-proof vest at a glancing angle. The mass of the vest and the dummy is 56.0 kg. The bullet-vest collision is inelastic.



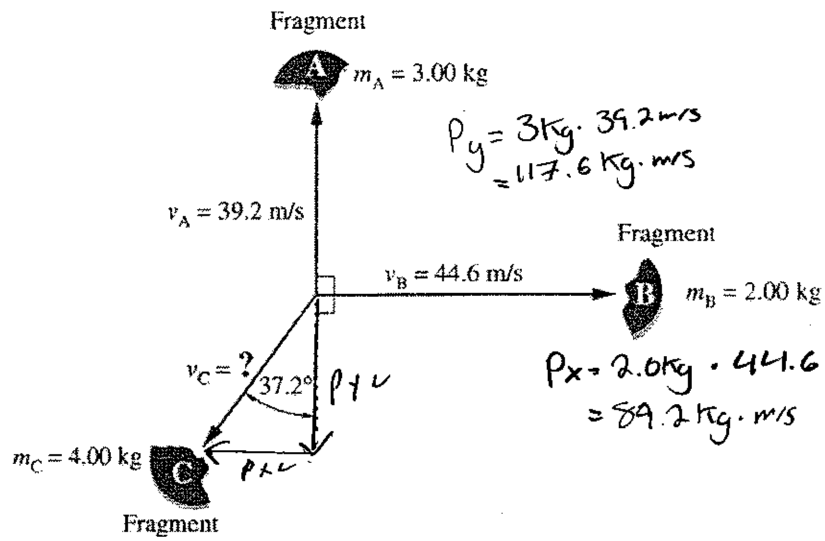
Example problem – Cosine method

The resultant velocity of the vest and the dummy following the glancing collision shown above, expressed in scientific notation, is $\boldsymbol{a.bc} \times 10^{-d}$ m/s at $\boldsymbol{e.fg}$ ° below the original path of the bullet. The values of ***a***, ***b***, ***c***, ***d***, ***e***, ***f***, and ***g*** are ____, ____, ____, ____, ____, ____, and ____.

Class problems

Use the following information to answer the next question.

Two–Dimensional Explosion



An explosion of a stationary object produces three fragments that move away from each other in a horizontal plane.

9. The speed, v_c, of fragment C is

(A) 36.9 m/s
B. 48.6 m/s
C. 51.7 m/s
D. 148 m/s

$P_{xb} = P_{xa}$

$0 = P_{Ax} + P_{Bx} + P_{Cx}$

$0 = 0 + 89.2 + P_{Cx}$

$-89.2 = P_{Cx}$

$P_{yb} = P_{ya}$

$0 = P_{Ay} + P_{By} + P_{Cy}$

$0 = 117.6 + 0 + P_{Cy}$

$-117.6 = P_{Cy}$

$P_c = \sqrt{(-89.2)^2 + (-117.6)^2}$

$P_c = \frac{147.6\ldots \text{ kg·m/s}}{4.00 \text{ kg}}$

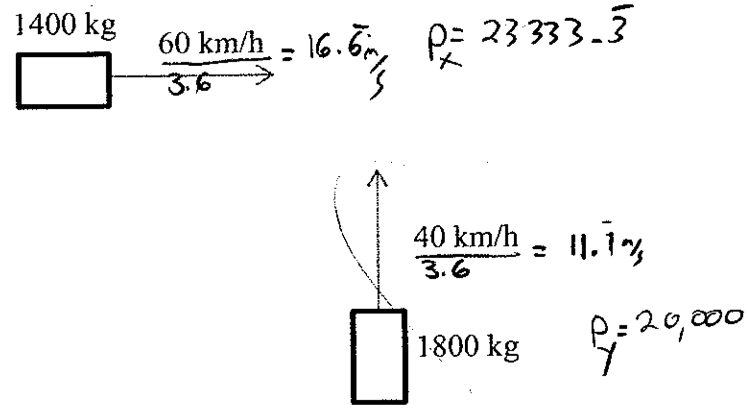
or just find one component and use angle to find resultant

$v = 36.9$ m/s

Dr. Ron Licht

Use the following information to answer the next question.

A 1400 kg car travelling east at 60 km/h collides with an 1800 kg car travelling north at 40 km/h.

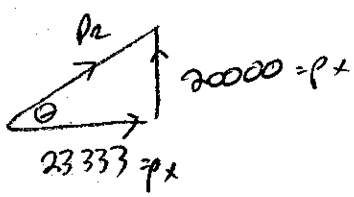


(The diagram is not drawn to scale)

3 1 4 1 **Numerical Response**

2. The momentum of the cars prior to the collision, expressed in scientific notation, is $a.b \times 10^4$ kg·m/s at ef° N of E. The values of a, b, e, and f are ____, ____, ____, and ____.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)



$\tan x = \frac{20,000}{23000}$

$= 41$

$p_R = \sqrt{(23333)^2 + (20000)^2}$

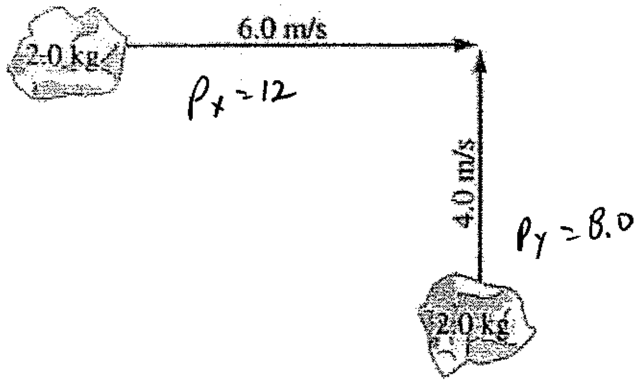
$= 3.1 \times 10^4$

$\tan \theta = \frac{20000}{23333.33}$

$\theta = 41°$ NE

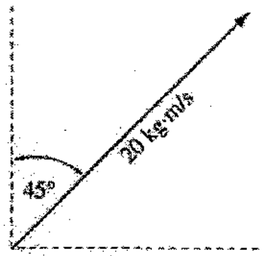
Use the following information to answer the next question.

A 2.0 kg lump of clay moving north at 4.0 m/s collides with another 2.0 kg lump of clay moving east at 6.0 m/s, as shown below.

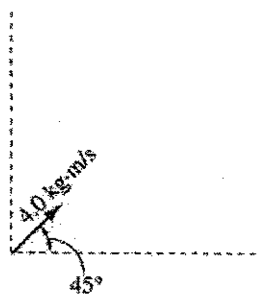


10. Which of the following diagrams shows the momentum of the system immediately after the collision?

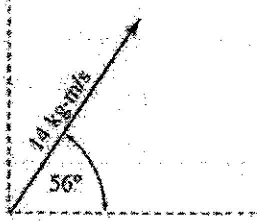
A.



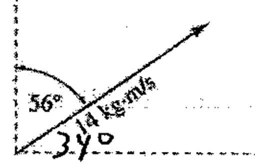
B.

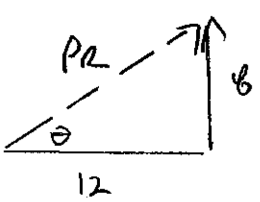


C.



(**D.**)





$P_r = \sqrt{(12)^2 + (8)^2}$

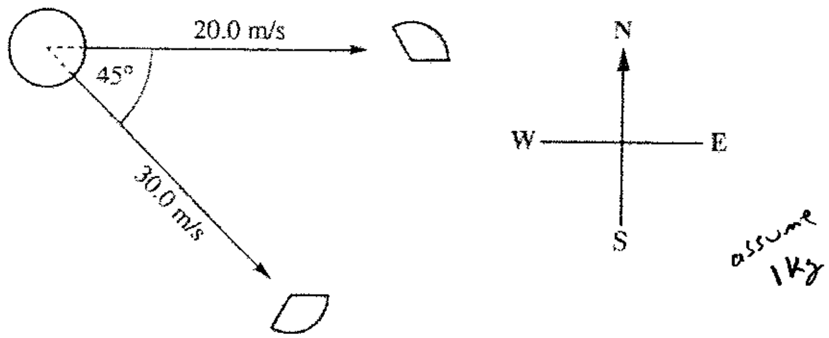
$= 14.4$ kg·m/s

$\tan\theta = \frac{8}{12}$

$\theta = 34°$

Use the following information to answer the next two questions.

A stationary bomb exploded in a street in the centre of a city. The three pieces of debris from the bomb, each of approximately the same mass, flew off horizontally in different directions. Analysis revealed that one piece moved east at 20.0 m/s, and a second piece moved southeast at 30.0 m/s.



11. The third piece of debris was difficult to locate. Where should investigators look for the third piece?

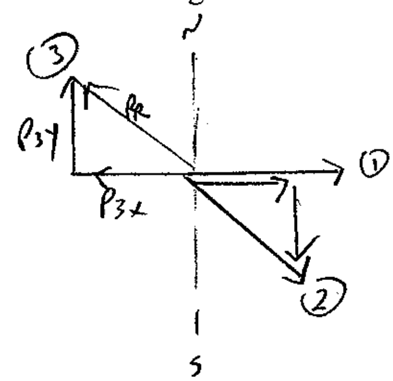
A. 27° W of N

(B.) 27° N of W

C. 22.5° S of W

D. 22.5° N of E

can't be possible →



Numerical Response

3. The speed of the third piece, expressed in scientific notation, is ***a.bc*** × 10^d m/s. The values of ***a***, ***b***, ***c*** and ***d*** are ____, ____, ____, and ____. 4.64 × 10^1

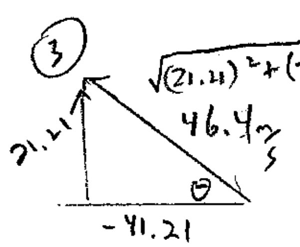
(Record your **four-digit answer** in the numerical-response section on the answer sheet.)

$p_{xb} = p_{xa}$

$0 = p_{1x} + p_{2x} + p_{3x}$

$0 = 20 + (\cos 45 \times 30) + p_{3x}$

$-41.21 = p_{3x}$



$\tan\theta = \frac{21.21}{41.21}$

$\theta = 27$ NW

$p_{yb} = p_{ya}$

$0 = p_{1y} + p_{2y} + p_{3y}$

$0 = 0 + (\sin 45 \times 30) + p_{3y}$

$21.21 = p_{3y}$

UNIT II – ELECTRIC FORCES AND FIELDS (25 – 35%)

Electrostatics

Electrostatics is the study of electric charge (electro) that is at rest (static). There are three types of particles of which all matter is composed:

	charge	relative mass
electrons	–1	1
protons	+1	1836
neutrons	0	1839

Since electrons are far less massive than protons, they are moved or removed far more easily than protons. Positive charges always stay put within the nuclei of atoms. Static electric charges are due to an **excess of electrons** (negative charge) or a **deficit of electrons** (positive charge).

The **Rules of Charge** are

- there are two types of electric charge (positive and negative)
- like charges repel each other
- unlike charges attract each other

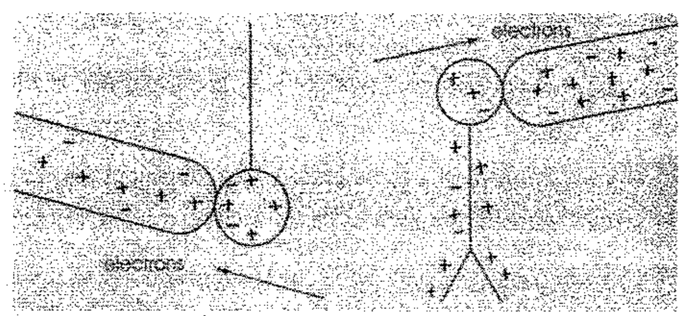
The **Law of Conservation of Charge** states that electric charge can neither be created nor destroyed but may be transferred. Matter can become electrically charged through three different processes – **friction, conduction** and **induction**.

Charging By Friction

An ebonite rod, for example, becomes charged when rubbed with fur. When ebonite and fur are rubbed together, some of the electrons from the fur are "captured" by the atoms of the ebonite. The ebonite has an excess of electrons (negatively charged) and the fur has a deficit (positively charged). The work done (i.e. friction force through a distance) results in a static charge.

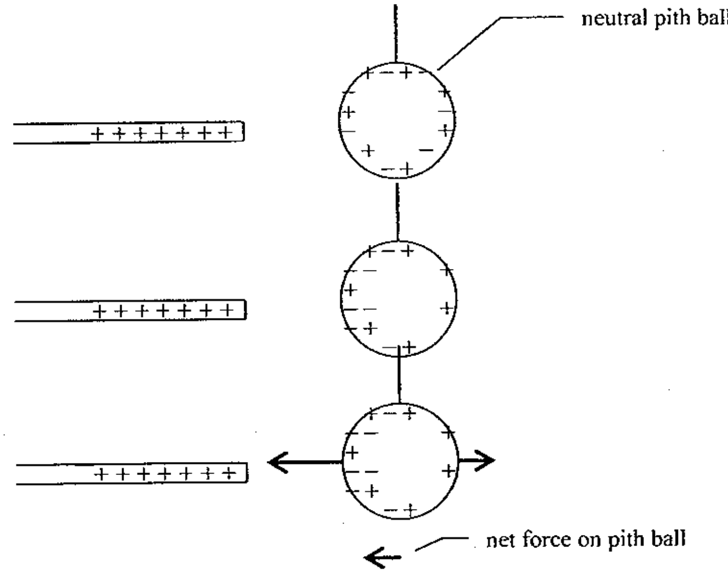
Charging by Conduction (Contact)

When a negatively charged rod is touched to a neutral conducting object, some of the excess electrons on the rod move over to the object. When a positively charged rod is used, some of the free electrons on the object are attracted over to the positive rod. Note, charging by **conduction** results in the object **receiving** the **same charge** as the charging device and the charging device loses some, not all, of its charge in the process.



Induced charge separation

When a charged rod is brought near a neutral pith ball initially nothing appears to happen, but after a few seconds the pith ball is attracted to the charged rod. To illustrate, suppose a charged rod, in this case a positive rod, is brought close to a neutral pith ball.

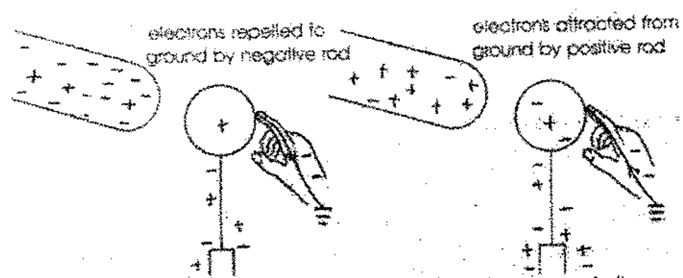


The negative charges on the pith ball are attracted to the charged rod resulting in a charge separation.

Since the negative side of the pith ball is closer to the rod than the positive side, the attractive force between the negative side of the pith ball and the rod is slightly greater than the repulsive force between the positive side of the pith ball and the rod. The result is a net force toward the rod.

Charging by Induction (influence or induce)

When a negatively charged rod is brought near the knob of a neutral metal-leaf electroscope, free electrons on the electroscope move as far away as possible from the negative rod. If you **ground** the electroscope with your finger, electrons are induced to flow away through your finger. When your finger is removed, the electroscope is left with a deficit of electrons and, therefore, a positive charge. Note that charging by **induction** causes the object to become **opposite** in charge to the charging device and the charging device does not lose any charge in the process.



Grounded electroscope in the presence of a negatively charged rod

Grounded electroscope in the presence of a positively charged rod

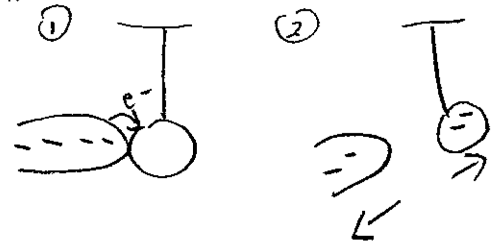
---

In general, the amount of excess charge that an object can hold is related to the **surface area** of the object. The charges will spread themselves as far apart from one another as they can due to mutual repulsion.

How easily charge flows on a body, or from one body to another, is dependent on the nature of the materials involved. Some materials are considered to be **conductors** (materials that readily allow the flow of charge) and other materials are **insulators** (materials that hinder the flow of charge).

12. *One way to give a graphite-coated sphere a negative charge is to touch it with a __ i __ charged rod. This process is called charging by__ ii __ .*

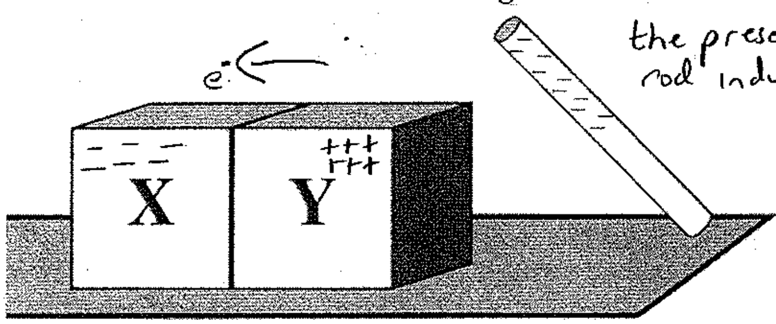
The statements above are completed by the information in row



Row	*i*	*ii*
A.	positively	induction
B.	positively	conduction
C.	negatively	induction
D.	negatively	conduction

Use the following information to answer the next question.

Movement of Charges



the presence of the negative rod induces a charge separation.

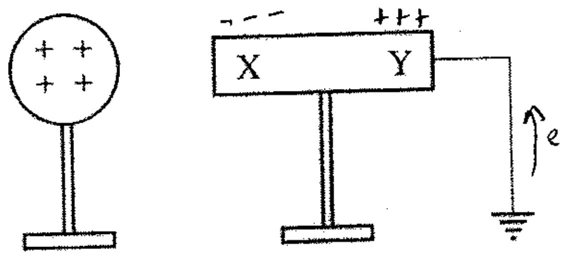
Two neutral metal objects (X and Y) are placed on a wooden table in contact with each other. A negatively charged rod is brought near object Y, and while the rod is nearby, the metal objects are separated without grounding.

13. Which statement correctly describes what has occurred after the charged rod was removed?

A. Object X received a negative charge by conduction, and object Y received a positive charge by conduction
B. Object X received a negative charge by induction, and object Y received a positive charge by induction
C. Objects X and Y both received a negative charge by induction
D. Objects X and Y both received a negative charge by conduction

Use the following information to answer the next question.

A student places a positively charged sphere near a metal rod. Both are on insulated stands and the rod is grounded.

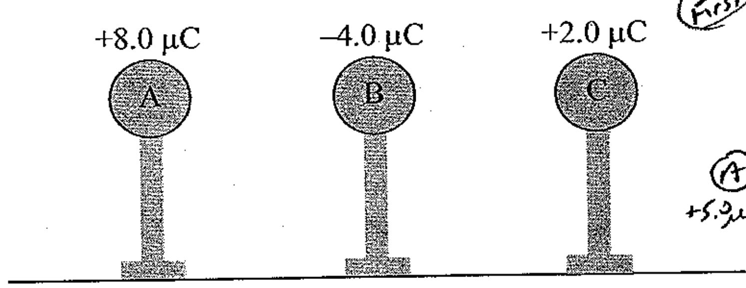


14. The distribution of charge on the rod is

A. positive at end X and electrons move off the rod into the ground
B. negative at end X and electrons move off the rod into the ground
C. positive at end X and electrons move onto the rod from the ground
D. negative at end X and electrons move onto the rod from the ground

Use the following information to answer the next question.

As illustrated below, three identical insulated spherical conductors A, B and C were given initial charges of +8.0 μC, –4.0 μC and +2.0 μC respectively.



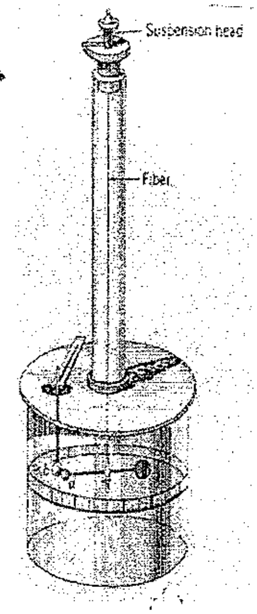
Numerical Response

4. Sphere A is touched to sphere C and then brought back to its original position. Then sphere A is touched to sphere B and then brought back to its original position. The magnitude of the final charge on sphere A, expressed in scientific notation, is $a.b \times 10^{-cd}$ C. The values of a, b, c, and d are 5, 0, 0, and 7.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

Electric Forces – Coulomb's Law

Charles Coulomb (1738 – 1806) tested the relationship between charge and distance between charges using a **torsion balance** which was similar to a device that Cavendish had used to measure the universal gravitational constant G. [redacted]agrammed to the right. The basic idea is that the force between the charges is directly proportional to the measured angle of twist (i.e – torsion) in the wire. By measuring the angle of torsion caused by the repulsion of charge (a) from charge (b), Coulomb had a way to measure the force of repulsion.



Coulomb tested the effect of the magnitude of the two charges and the distance between them. He found that the electrostatic force varied directly as the product of the two charges and inversely as the square of the distance between the two charged objects.

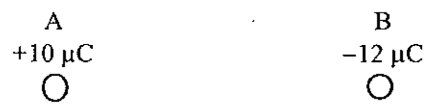
$$F \propto \frac{q_1 q_2}{r^2}$$

After repeated measurements where the charges and distances were known, he was able to replace the proportionality sign $\propto$ with (k) which is now known as Coulomb's constant ($k = 8.99 \times 10^9\ N{\cdot}m^2/C^2$). The final result is known as [redacted]w of electrostatic attraction.

$$|F_e| = k\frac{q_1 q_2}{r^2}$$

where F is in newtons (N), q is in coulombs (C), r is in metres (m) and k is "Coulomb's constant".

I strongly recommend that **Coulomb's Law** be used to calculate the **magnitude** of the force, while the **Law of Charges** and the **specific situation** or **context** is used to indicate the **direction** of the force. Consider the situation diagrammed to the right and we are asked to calculate the force acting on charge A. Using Coulomb's Law

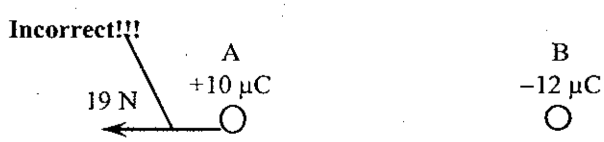


$$F_e = k\frac{q_A q_B}{r^2}$$

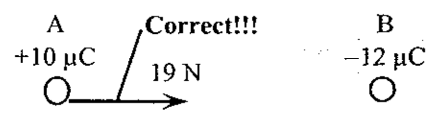
$$F_e = \frac{8.99\times10^9 \frac{N m^2}{C^2}(+10\times10^{-6}C)(-12\times10^{-6}C)}{(0.25m)^2}$$

$$F_e = -17N$$

The magnitude of the force between A and B is 17 N, but what does the negative sign mean in this context? At this point many students make the mistake of drawing the force vector on A in the negative (left) direction.



The Law of Charges indicates that A is attracted to B, which, in the context of the given situation, is in the positive (right) direction. Therefore, think of Coulomb's Law as an **absolute value equation.**



15. Two identical charged spheres are a distance r apart and the force between them is F. When the distance between them is changed to (2/3) r, the force between the sphere's becomes

A. $\frac{4}{9}F$

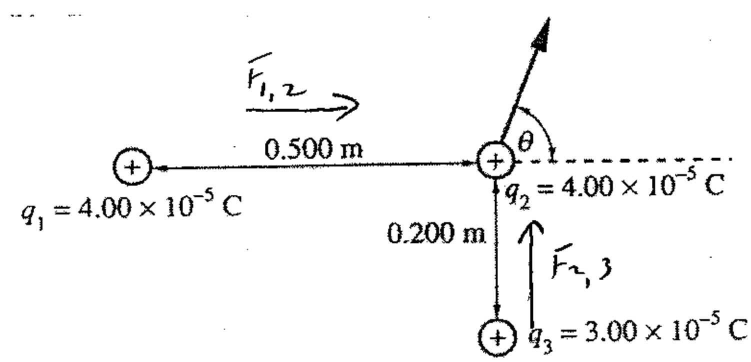
B. $\frac{2}{3}F$

C. $\frac{3}{2}F$

D. $\frac{9}{4}F$

Use the following information to answer the next two questions.

Three charges, q_1, q_2, and q_3, are placed at the vertices of a right angle triangle, as shown below.



16. The magnitude of the net electrostatic force acting on q_2 is

A. 212 N
B. 263 N
C. 276 N
D. 327 N

Numerical Response

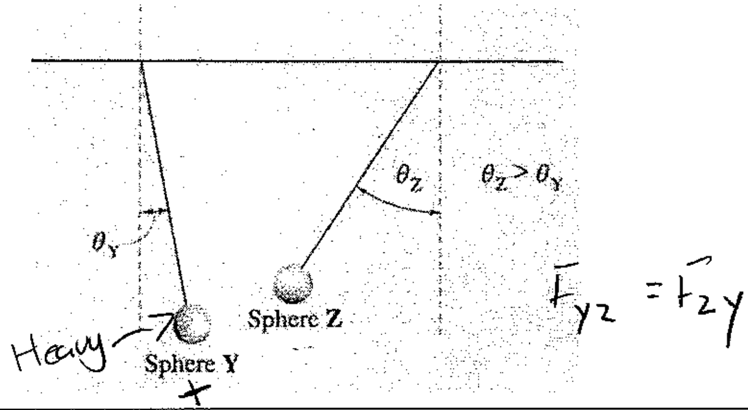
5. The angle labeled θ indicates the direction of the net electrostatic force on q_2. The value of θ is ***ab.c*** °. The values of ***a***, ***b*** and ***c*** are ____, ____, and ____.

(Record your **three digit** answer in the numerical-response section on the answer sheet.)

pay attention to this!!

Use the following information to answer the next three questions.

In an electrostatics demonstration, a teacher uses two graphite-coated spheres, Y and Z, that are suspended on insulating threads. She tells the students that sphere Y is positively charged. She does not provide any information about sphere Z. The spheres hang in equilibrium as shown below. The angle θ_Z is greater than the angle θ_Y.



17. Which of the following conclusions comparing either the charges present on spheres Y and Z or the masses of spheres Y or Z is supported?

   A. Sphere Y has more charge than sphere Z and is therefore deflected from the vertical by a smaller angle.

   B. Sphere Z has more charge than sphere Y and is therefore deflected from the vertical by a larger angle.

   C. Sphere Y has more mass than sphere Z and is therefore deflected from the vertical by a smaller angle.

   D. Sphere Z has more mass than sphere Y and is therefore deflected from the vertical by a larger angle.

18. The nature of the charge on sphere Z must be

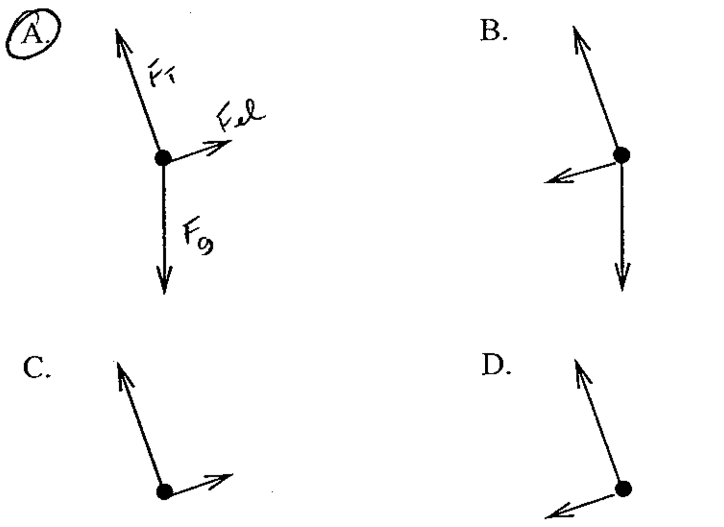
   A. positive only

   B. negative only

   C. either positive or neutral

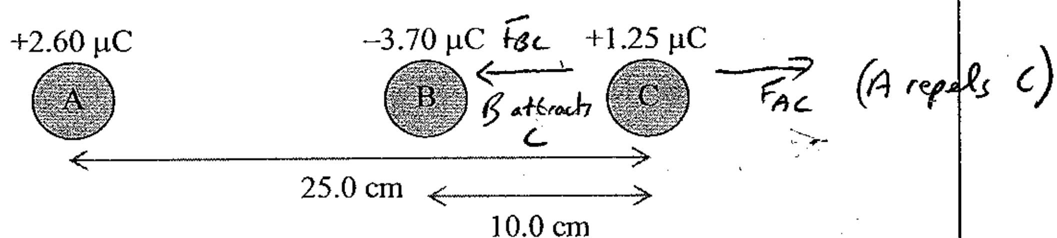
   D. either negative or neutral

19. Which of the following free-body diagrams most closely represents the forces acting on sphere Y?



Use the following information to answer the next question.

Three identical insulated spherical conductors A, B and C were given charges of +2.60 μC, –3.70 μC and +1.25 μC respectively. Sphere A is placed 25.0 cm to the left of sphere C and sphere B is placed 10 cm to the left of sphere C.



(The diagram is not drawn to scale)

20. The net force acting on sphere C is

(A.) 3.69 N to the left

B. 3.69 N to the right

C. 4.63 N to the left

D. 4.63 N to the right

$F_{AC} = \frac{K \cdot 2.6e^{-6} \cdot 1.25e^{-6}}{(.25)^2} = 0.467\ N\ [E]$

$= 3.69\ N$

$F_{BC} = \frac{K \cdot 3.7e^{-6} \cdot 1.25e^{-6}}{(.1)^2} = 4.1578\ N\ [W]$

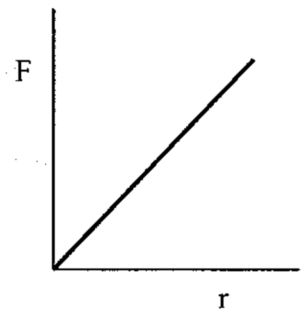
$F_{net} = F_{BC} - F_{AC} = 4.1578 - 0.467 = 3.69\ N\ [W]$

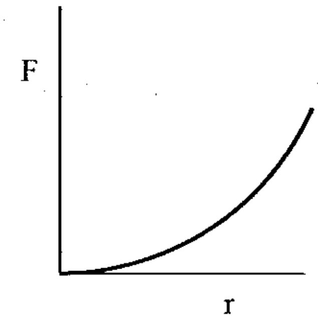
Use the following information to answer the next two questions.

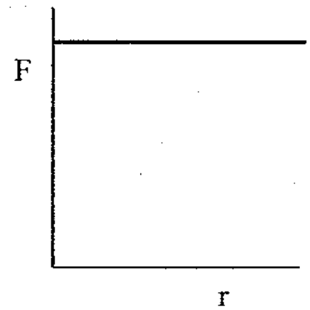
A student performed an experiment that verified Coulomb's Law of Electrostatics by measuring the repulsion between two charged spheres as a function of the separation of the spheres. The spheres were identical in size and mass.

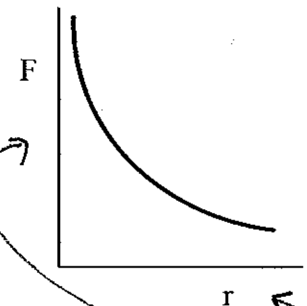
21. The student constructed a graph of the **Force of Repulsion as a Function of the Separation**. The correct graph would appear as:

main formula $F_{el} = k\frac{q_1 q_2}{R^2}$

A


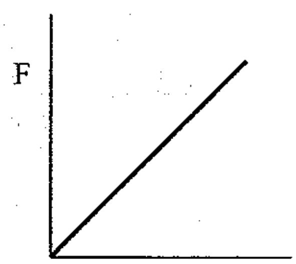
B


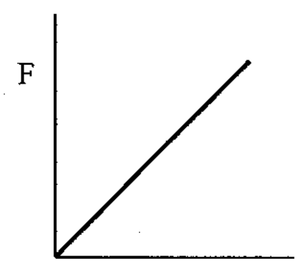
C


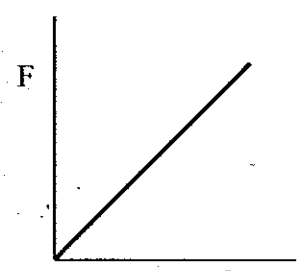
(D)


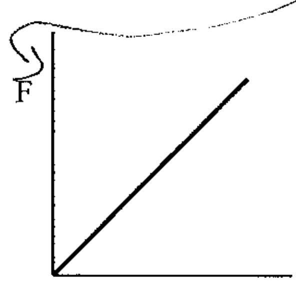
$F_{el} \propto \frac{1}{R^2}$

22. Which of the following is **also** a graph of the **Force of Repulsion as a Function of the Separation**?

A


B


C


(D)


F_{el}	R	$\frac{1}{R^2}$
1	1	1
.25	2	.25
.11	3	.11

Dr. Ron Licht

Electric Fields

A **field** can be loosely described as a "region of influence" is space. **Electric fields influence electric charges.** Electric fields are **vector fields** – they have magnitude and direction. The direction of an electric field is defined as the **direction that a positive test charge would move** if placed in the field. The magnitude of an electric field may be calculated using:

$$\left|\vec{E}\right| = \frac{\vec{F}_e}{q_o}$$ The units for electric field strength are N/C and V/m.

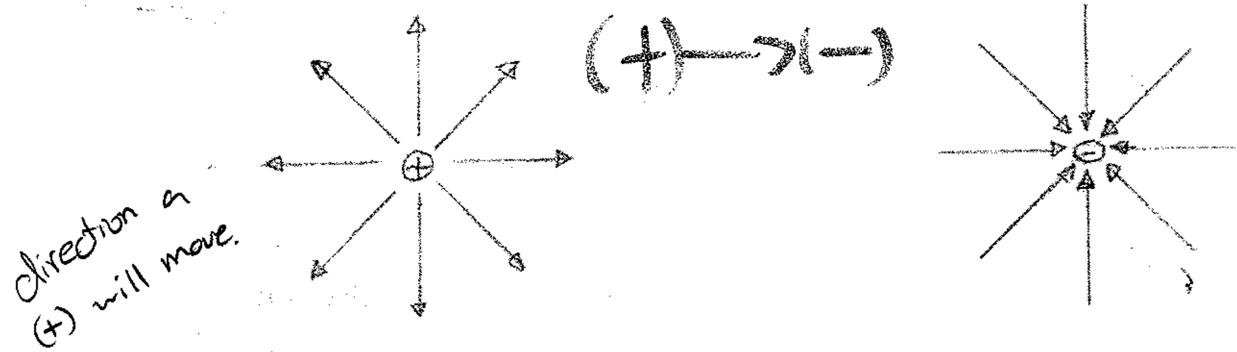
q_o → respording to field

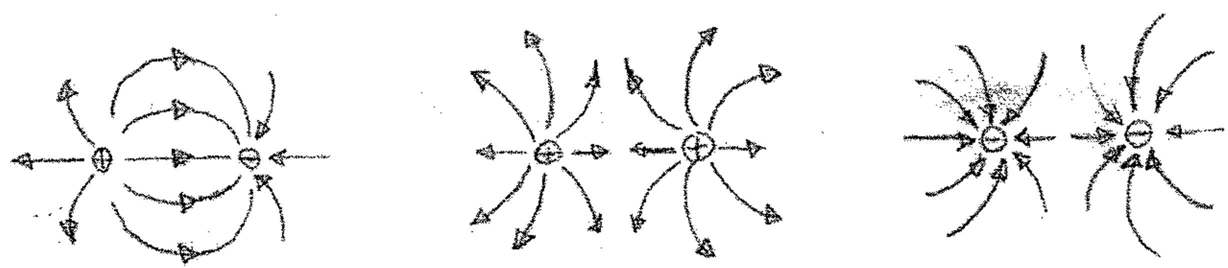
The magnitude of the electric field created by a **point charge** (q) is

$$\left|\vec{E}\right| = k\frac{q}{r^2}$$ q → creating field

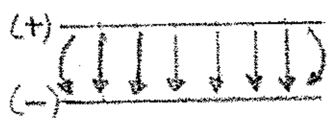
If more than one charge is present, the total field present at any point in space is found by finding the sum of all individual fields present at that point. Since electric fields are vector fields, the resultant field is calculated using **vector addition**.

Field diagrams:
Fields are often shown as "field lines." The density of the lines represents the strength of the field and an arrow indicates the direction of the field line. Note that the fields around point charges are **non-uniform fields** – the field line density becomes smaller away from the charge.





Fields associated with parallel charged plates are shown as a set of parallel lines that are perpendicular to the plates. The field between the plates is a **uniform electric field**.



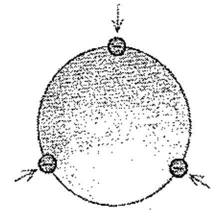
$\left|\vec{E}\right|$ with → means electric fields *

Many electrical applications involve moving charges between two opposite charged parallel plates. In this case, the electric field strength is calculated using

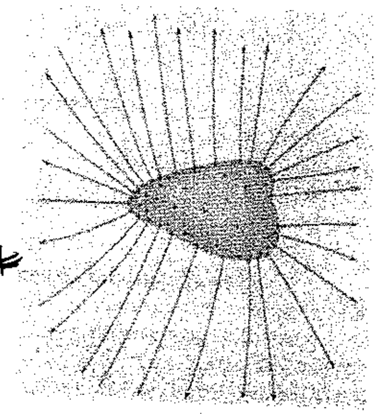
parallel plates $$\left|\vec{E}\right| = \frac{\Delta V}{\Delta d}$$ where V is the electric potential and d is the distance between the plates.

* E with no → is electric energy *

Conductors and Electric Fields



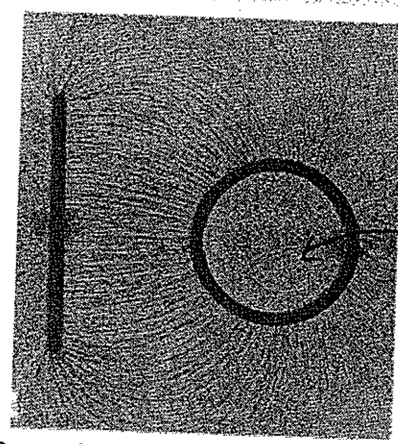
In a conductor, electrons move freely until they reach a state of [redacted] – i.e. [redacted]. For example, when a solid metal sphere is charged, either negatively or positively, all excess charges move as far apart as possible because of electrostatic forces of repulsion. The result is that excess charges **distribute evenly on the surface of the sphere**.



✱ For an irregularly shaped conductor, the charges still repel one another and accumulate on the outer surface. As a rule, the net electrostatic forces cause the charges to accumulate at the points of an irregularly shaped convex conducting object. Conversely, the charges will spread out on an irregularly shaped concave conducting object. [redacted]

possible diploma. ✱

Electric fields within conductors



Imagine a neutral conductor, solid or hollow, in a field–free region of space. Now suppose we add some electrons to it, either on the surface or inside. Within a fraction of a second the distribution of charges is such that each free charge experiences a zero net force. If none of the charges experiences a net electric force, none of them is in an electric field. Since electric field lines either begin or end on charge, the field could only extend inside the conductor if there were a remaining excess of free charges there. **The electric field inside a charged conductor, anywhere beneath the surface, is zero.** (In the picture to the right note that there is no field within the circular charged conductor.)

electric shielding!

Movement of Charged Particles – Electric Fields and Electric Potential

Since charged particles experience forces when in electric fields they will experience **accelerations** and will have a corresponding change in **kinetic energy**. When given a question that asks for an **acceleration** to be calculated, it is better to use concepts relative to **forces**. Acceleration is calculated using a combination of

$$\vec{F}_{net} = m\vec{a} \quad \text{and} \quad |\vec{E}| = \frac{F_e}{q_o}$$

[redacted]

$$m\vec{a} = q_o|\vec{E}|$$

$$\vec{a} = \frac{q_o|\vec{E}|}{m}$$

acceleration, electric field

On the other hand, if you are asked to calculate the final [redacted] of a particle that is subjected to an electric field, it is best to approach the problem from a conservation of **energy** point of view using electric potential. While an electric field is defined in terms of the amount of force it exerts on a unit of electric charge, an **electric potential** is the amount of electric potential energy on a unit of electric charge. Electric potential is represented by V and is measured in J /C or in volts (V).

$$\Delta V = \frac{\Delta E}{q}$$

or $$\Delta E = q\Delta V$$

$$\Delta E_p = \Delta E_k$$

$$q\Delta V = \tfrac{1}{2}mv^2$$

$$v = \sqrt{\frac{2q\Delta V}{m}}$$

Make sure you know how to apply the **conservation of energy principle**.

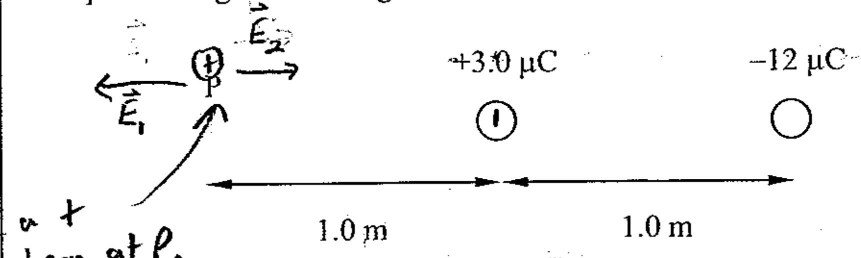
speed, electric field.

or $qV = \frac{1}{2}m\vec{v}_f^2 - \vec{v}_i^2$ if $v_i \neq 0$

Dr. Ron Licht

Use the following information to answer the next question.

Two point charges are arranged as shown.

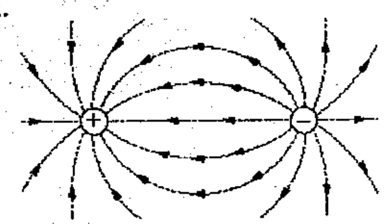


23. The magnitude of the net electric field at point P due to the two point charges is

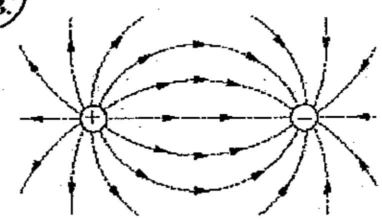
A. 5.4×10^4 N/C
B. 4.5×10^4 N/C
C. 2.7×10^4 N/C
D. 0.0 N/C

24. The electric field between a positive point charge and a negative point charge is represented by

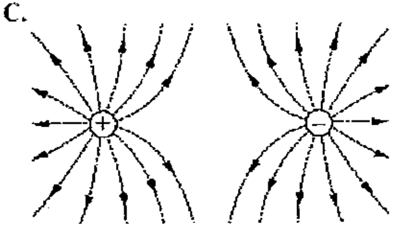
A.



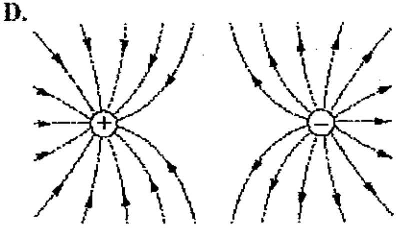
B.



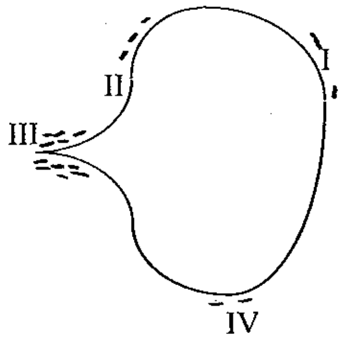
C.



D.



25. A metal plate is cut into an irregular shape as shown to the right. If electrons are placed on the plate, which point will have the greatest electric field strength?

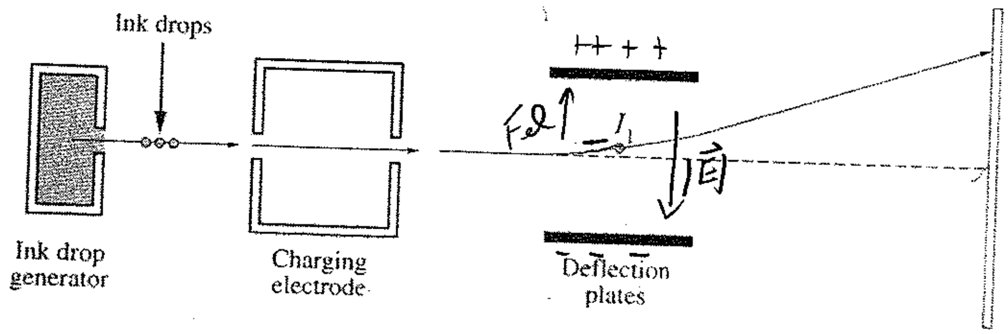


A. I
B. II
C. III
D. IV

Use the following information to answer the next four questions.

Side View of the Components of an Ink-jet Printer

The essential components of one type of ink-jet printer are shown below.



Ink drops from the generator pass through a charging electrode. By means of a signal from a computer, the charging electrode controls the charge given to the ink drops. Ink drops are deflected between the deflection plates. The amount each drop is deflected determines where it strikes the paper. A typical ink drop has a mass of 1.32×10^{-10} kg. Approximately 100 ink drops are needed to form a single letter on paper.

Ink drop I_1 has a charge of -1.51×10^{-13} C.

Numerical Response

$1.51\times10^{-13} C \times \frac{1 e^-}{1.60\times10^{-19} C} = 9.44\times10^{5} e^-$

6. The number of excess electrons given to ink drop I, expressed in scientific notation, is $a.bc \times 10^{d}$ electrons. The values of a, b, c, and d are __9__, __4__, __4__ and __5__.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

26. The deflection plates are 0.100 mm apart, and there is a potential difference of 120 V across them. The magnitude of the electric field between the plates is

(A.) 1.20×10^{6} N/C
B. 1.20×10^{3} N/C
C. 1.20×10^{1} N/C
D. 1.20×10^{-2} N/C

$|E| = \frac{Volts}{d} = \frac{120 V}{0.100\times10^{-3} m} = 1.20\times10^{6} N/C$ or V/m

27. As the charged ink drop, I_1, moves through the deflection plates it experiences a force with a magnitude of

test charge!

A. 1.81×10^{-15} N
B. 1.81×10^{-12} N
C. 1.81×10^{-10} N
(D.) 1.81×10^{-7} N

$F_{el} = q|\vec{E}| = 1.51\times10^{-13} C \times 1.20\times10^{6} N/C = 1.81\times10^{-7} N$

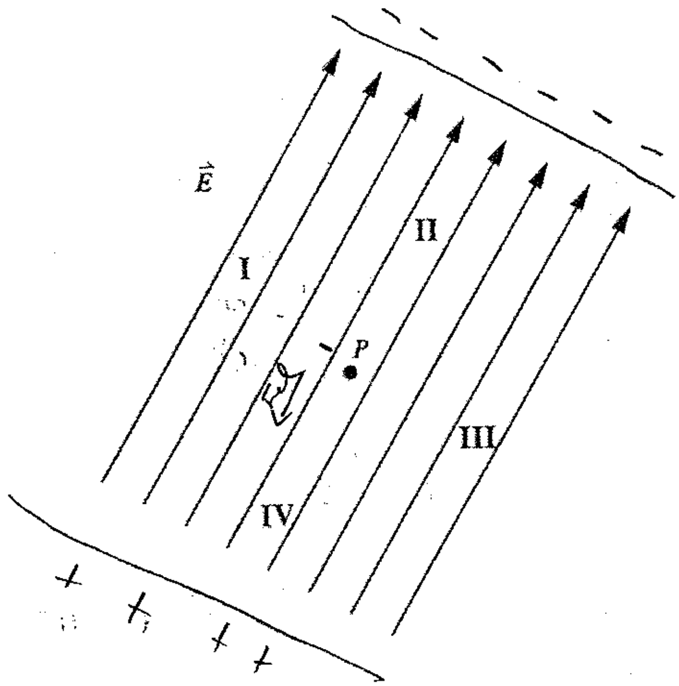
28. To cause ink drop I_1 to follow the path shown, the direction of the electric field between the charged deflection plates must be toward the

(A.) bottom of the page
B. top of the page
C. right of the page
D. left of the page

see diagram
note that F_{el} is up but
$|\vec{E}|$ is from + → −

Use the following information to answer the next question.

Electric Field



The parallel arrows represent the direction of an electric field.

29. An electron is placed at point P. It will accelerate toward region

A. I
B. II
C. III
(D.) IV

Use the following information to answer the next two questions.

Spark Plugs

In an automobile, a transformer is used to produce the high voltage that causes sparks in the spark plugs. The required voltage is 20 000 V. This voltage is high enough to cause a spark to jump across the 2.0 mm gap of a spark plug. This spark ignites the gasoline-air mixture in the automobile's cylinder.

Numerical Response

7. The speed of the electrons when they reach the other side of the gap of the spark plug, expressed in scientific notation, is $a.b \times 10^{cd}$ m/s . The values of *a*, *b*, *c*, and *d* are 8, 4, 0, and 7.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

$\downarrow E_p = \uparrow E_k$

$qV = \frac{1}{2}mv^2$

$1.6e^{-19} \cdot 20{,}000 = \frac{1}{2}(9.11e^{-31})(v)^2$

$3.2\times10^{-15} = 4.555\times10^{-31}\, v^2$

8.4×10^{7} m/s $= v$

Numerical Response

8. The acceleration of the electrons across the gap of the spark plug, expressed in scientific notation, is $a.b \times 10^{cd}$ m/s^2. The values of *a*, *b*, *c*, and *d* are 1, 8, 1 and 8.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

$F_{el} = ma$

$q|\vec{E}| = ma$

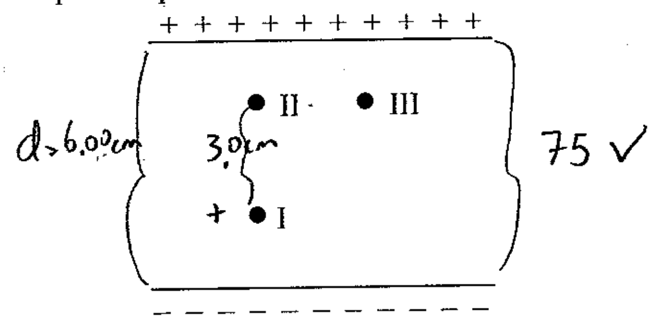
$1.60\times10^{-19}\left(\frac{20000}{2.0\times10^{-3}}\right) = 9.11\times10^{-31}\cdot a$

$1.60\times10^{-12} = 9.11\times10^{-31}\cdot a$

1.8×10^{18} m/s^2 $= a$

Use the following information to answer the next question.

Two parallel plates are 6.00 cm apart with a potential difference of 75.0 V across the plates. A proton is initially placed at the position marked I between two parallel plates.



(The diagram is not drawn to scale.)

30. The proton is moved 3.00 cm from position I to position II. It is then moved 3.00 cm from position II to position III. The difference in potential between points I and III is

A. 0 V

(B) 37.5 V

C. 53.0 V

D. 75.0 V

Note: work is done against the field in moving from I → II; there is no potential difference between II → III

$(\Delta E)\ W = F_{el}\, d$

$= q\,|E| \cdot (d \text{ against field})$

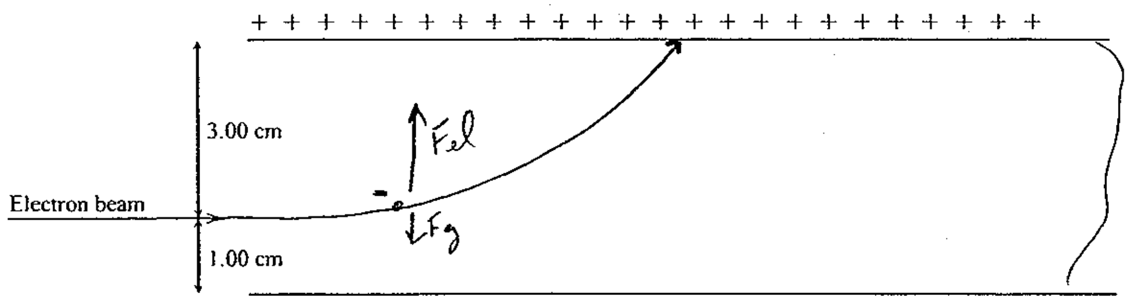
$= (1.60 \times 10^{-19})\left(\frac{75}{0.06}\right) \cdot 0.03 \text{ m}$

$= 6.0 \times 10^{-18}\ \text{J}$

$V = \frac{\Delta E}{q} = \frac{6.0 \times 10^{-18}\ \text{J}}{1.60 \times 10^{-19}\ \text{C}} = 37.5\ \frac{\text{J}}{\text{C}}$ or Volts

Use the following information to answer the next two questions.

Two horizontal plates are separated by a distance of 4.00 cm. The electric potential between the plates is 120 V. A horizontal beam of electrons, with a speed of 6.50×10^6 m/s, is directed into the electric field between the plates. The electrons enter the field 1.00 cm above the negative plate.



.04m

(The diagram is not drawn to scale.)

Horizontal stays constant. (uniform) vertical is accel by Fel

Numerical Response

9. The horizontal distance that the electrons travel before striking the positive plate is ______ cm.

	x (horizontal) uniform	y (vertical) accel
	$d = ?$	$d = 0.03\,m$
	$v = 6.50 \times 10^6\ m/s$	$v_i \neq 0$ (vertical)
	$t = ?$	$t =$
		$a = 5.26 \times 10^{14}\ m/s^2$

③ find d horizontal

$d = vt$

$= 6.50 \times 10^6\ m/s \cdot 1.067 \times 10^{-8}\ s$

$d = 0.0694\ m$

6.94 cm

② Find time

$d = \frac{1}{2} a t^2$

$0.03 = \frac{1}{2}\, 5.26 \times 10^{14} \cdot t^2$

$1.067 \times 10^{-8}\ s = t$

① Find upward accel

$F_{net} = F_{el} - F_g$

$ma = q|E| - mg$

$9.11 \times 10^{-31} \cdot a = (1.6 \times 10^{-19})\left(\frac{120V}{0.04}\right) - 9.11 \times 10^{-31} \cdot 9.81$

$9.11 \times 10^{-31} \cdot a = 4.8 \times 10^{-16}\,N - 8.936 \times 10^{-30}\,N$

negligible compared F_e

$a = 5.26... \times 10^{14}\ m/s^2$

Use the following additional information to answer the next question.

Two of the following physics principles were used in the calculation of the horizontal distance.

1. uniform motion (balanced forces)
2. uniformly accelerated motion (unbalanced forces)
3. circular motion (unbalanced forces)
4. conservation of momentum
5. conservation of energy
6. conservation of mass-energy
7. conservation of charge
8. conservation of nucleons
9. wave-particle duality

Numerical Response

10. In the **correct order**, the principles that were applied in the horizontal distance calculation from Numerical Response 9 were 2 and 1. or 1 and 2

(Record your **two digit** answer in the numerical-response section on the answer sheet.)

Electric Current

When charge is allowed to flow through a conductor, the flow is called electric current. **[redacted]rrent** (I) is defined as the [redacted] that passes a point in a unit of [redacted].

$I = \frac{q}{t}$ [redacted]

The units for electric current is C/s or the ampere (A). (Note: The ampere is a fundamental SI unit just as are the metre, kilogram and second.)

There are two ideas about current. Before electrons were discovered, physicists assumed that current flowed from the positive terminal to the negative terminal of a battery. In other words, current was the flow of positive charges. This **assumption** about the direction of the electric current is called **conventional current**. (+)

Much later, after the conventional current assumption had become firmly entrenched in scientific literature, the electron was discovered. It soon became clear that current was actually the flow of negatively charged electrons from the negative terminal to the positive terminal of the battery. This model is called [redacted]. (−) assume e^-

Use the following information to answer the next question.

> *Torpedo occidentalis is* a large electric fish that uses electricity in attack and defense. A typical individual fish is capable of producing potential differences of up to 220 V and of generating pulses of 15.0 A current through its seawater environment. Pulses are typically 2.00×10^{-3} s in duration.

31. The total charge transferred by the fish in one of these pulses is

(A.) 3.00×10^{-2} C
B. 4.40×10^{-1} C
C. 3.00×10^{3} C
D. 3.30×10^{3} C

$I = \frac{Q}{T}$

$15 = \frac{Q}{2e^{-3}}$

$3.00 \times 10^{-2} C = q$

32. The equivalent SI unit for charge is

A. $\frac{A}{s}$

(B.) $A \cdot s$

C. $\frac{N \cdot s \cdot T}{m}$

D. $\frac{N \cdot s \cdot m}{T}$

$I = \frac{q}{t}$

$q = I \cdot t$

$=$ Amps • seconds

Magnetism

The Rules for Magnetism are:

⇒ Magnets always have [redacted]poles. Single poles do not exist.

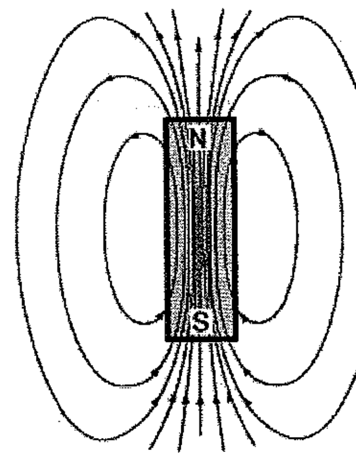
⇒ [redacted]el.

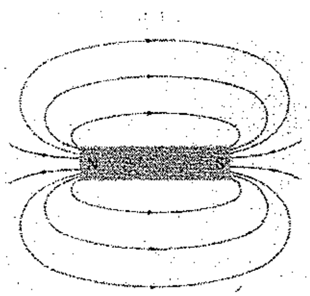
⇒ [redacted]act.

Do not confuse North-South magnetic poles with + and – charges. Magnetic poles do not attract or repel electric charges.

Magnetic fields

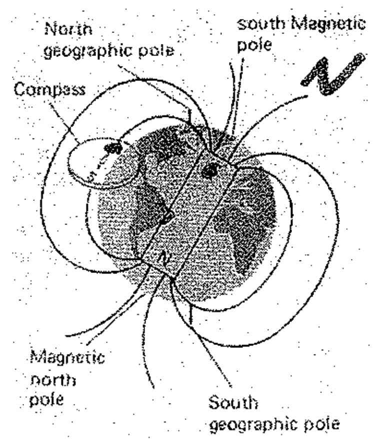
Magnetic fields are vector force fields and are symbolized as **B**. The unit used for magnetic fields is the **tesla** (T). The shape and direction of magnetic fields can be shown in field diagrams. In a diagram of a magnetic field, the magnetic field is represented by **magnetic lines of force**. It must be noted that, as the diagram to the right illustrates, the magnetic field lines continue through the magnetic domains within the magnet and are therefore **continuous closed loops**. Whereas gravitational field lines originate from a mass and electric field lines originate from positive charges, [redacted]





The majority of the time we only draw the field lines of interest. For a bar magnet we draw the external field lines to represent the magnetic field. The [redacted] of any magnetic field is defined as the direction in which the [redacted] will point when placed in the field.

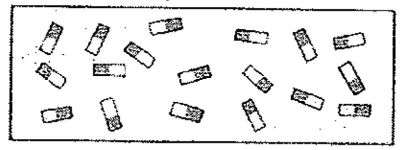
The Earth has a magnetic field that acts as if it had a giant magnet inside. The north magnetic pole of a compass points toward the geographic north pole. Since magnetic north is attracted to magnetic south, there must be a [redacted] located near the [redacted]. Likewise, a north magnetic pole exists near the south geographic pole. Note that the magnetic poles do not occur at the geographic poles – there is an angle (i.e. angle of declination) between the geographic pole and the magnetic pole.



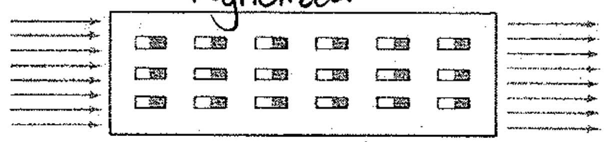
North pole (S)

South pole (N)

Natural Magnetism



Only certain materials can either be made into a permanent magnet or be attracted by a magnetic field. These kinds of materials are called **ferromagnetic** substances. According to the domain theory of magnetism, all ferromagnetic substances are composed of a large number of regions (less than 1 μm long) called **magnetic domains**. Each domain behaves like a tiny bar magnet. When a ferromagnetic object is in an unmagnetized state, the millions of [redacted] so that their combined [redacted].



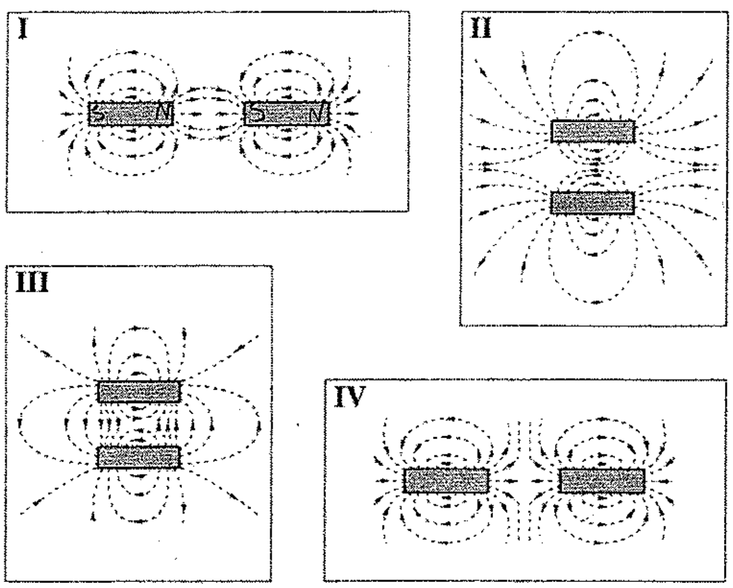
However if a ferromagnetic object is placed in a strong enough magnetic field, some of the [redacted] rotate to [redacted] with the [redacted] The net result is that a preferred orientation of the domains (in the same direction as the external field) [redacted]. When the external magnetic field is removed, this orientation may remain for a long time or may disappear immediately depending on the type of material.

Iron, Cobalt, Nickel
ferromagnetic

Use the following information to answer the next question.

Magnetic Fields Around Two Bar Magnets

attract



33. Given the magnetic fields illustrated above, the magnets will repel in diagrams

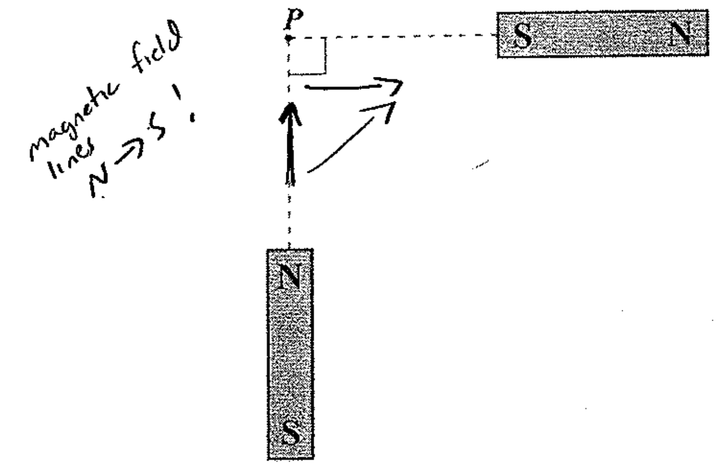
A. I and II only
B. II and III only
C. I and IV only
(D) II and IV only

34. Magnets can be produced when small magnetic regions in a metal line up their poles. These magnetic regions are called magnetic

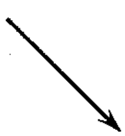
A. domains
B. fields
C. atoms
D. areas

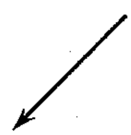
Use the following information to answer the next question.

Two bar magnets of equal magnetic strength are placed as shown below. The point P is the same distance from each of the magnets.



35. The direction of the magnetic field at **P** due to the two bar magnets is

A. 

B. 

C. 

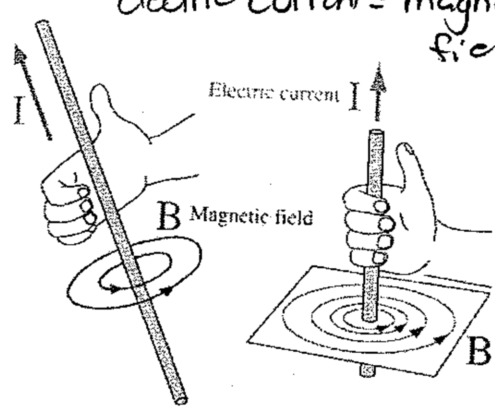
D. 

.romagnetism

.ans Christian Oersted demonstrated that a compass is deflected when placed near a current carrying conductor. The key idea is that **electric currents in conductors induce a magnetic field around** the conductor. Further, the magnetic field is in a plane **perpendicular** to the conductor. Electric fields and magnetic fields are always perpendicular to one another.

The direction of the magnetic field can be determined using hand rules. For all hand rules, when we consider the movement of positive charges (i.e. **conventional current (I)** flow) we use the **right hand**. When consider the movement of negative charges (i.e. **electron flow (e⁻)**) we use the **left hand**. straight wire.

electric current = magnetic field.

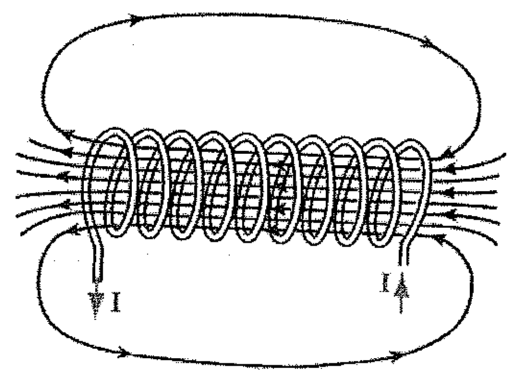


Hand Rule #1.

⇒ the extended **thumb** indicates the direction of current/electron flow

⇒ **fingers** curled around the thumb indicates the direction of the magnetic field around the conductor

When a long conducting wire is bent into a loop, the magnetic field from each point in the loop points in the same direction. The result is a strong magnetic field inside the loop of wire. If wire is wrapped repeatedly we have a coil of wire (i.e. – a **solenoid**). This is called an **electromagnet** since the electric current through the loops of wire results in a strong, uniform magnetic field. The strength of the electromagnet will depend on the number of loops in the solenoid and the amount of current flowing through the loops.

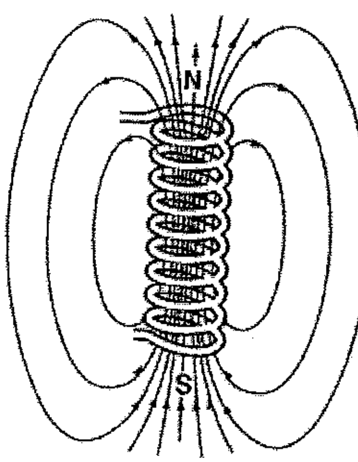


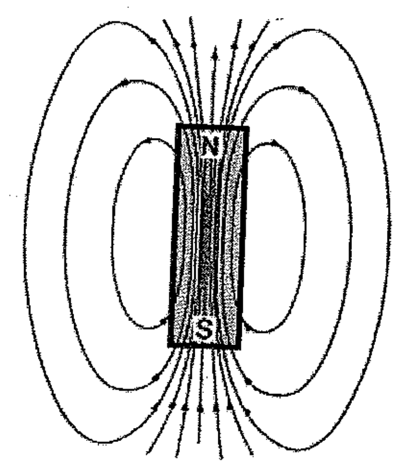
electromagnet. (loops)

To determine the direction of the magnetic field in the core of the solenoid, we use **Hand Rule #2**.

⇒ The **fingers** curl in the direction of the current (right hand) or the electron flow (left hand).

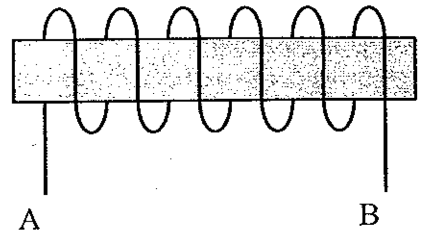
⇒ The **thumb** will point in the direction of the magnetic field lines in the core of the solenoid and, hence, toward the **north pole** of the electromagnet.



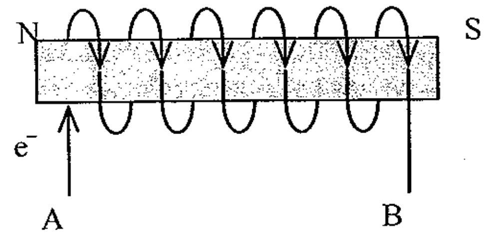


Example

In the diagram below if electrons flow from A to B, which end of the coil is north?



solution – Draw in arrows on the solenoid to indicate the direction of electron flow. The fingers of the left hand (e^- flow) wrap around the coil in the direction of the electron flow and the thumb points to indicate the North end of the electromagnet.



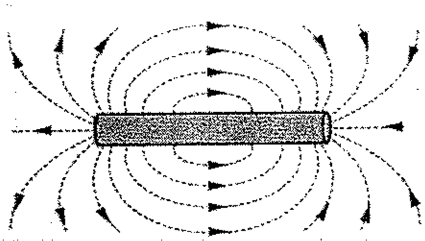
Thumb points towards N.

Use the following information to answer the next question.

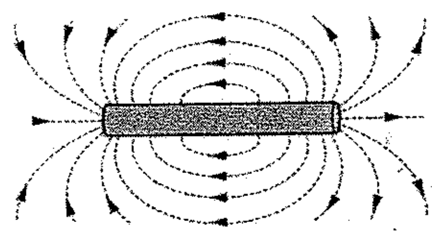
A negatively charged rubber rod is moved from left to right.

36. The magnetic field induced around the rubber rod as it moves is represented by

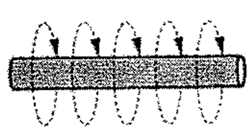
A.



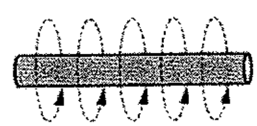
B.



C.

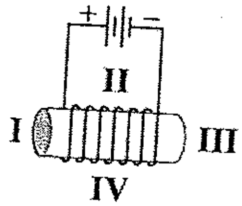


D.



1st hand rule!

The north pole of the solenoid shown below is at position



(−) → (+)

2nd hand rule.

A. I
B. II
C. III
D. IV

Magnetic Forces

A current carrying conductor is within an external magnetic field experiences a force.

$$|\vec{F}_m| = I L_{\perp} |\vec{B}|$$

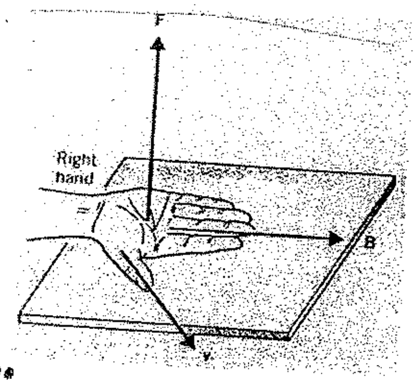
A m T

Where I is the current (A)
B is magnetic field strength (T)
L is the length of wire in the field (m)

The understanding of this force led to the development of electric motors. For this reason, the action of this force is often referred to the **[redacted] effect**.

For the situation when a charged particle is in an external magnetic field the equation is

$$|\vec{F}_m| = q v_{\perp} |\vec{B}|$$

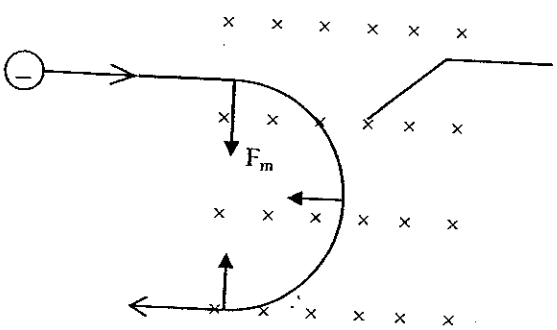


The direction of the magnetic force on either a conductor or a particle can be determined using **Hand Rule #3**. The hand is flat with the thumb pointing perpendicular with the fingers:

⇒ the extended [redacted] points in the direction of the [redacted]/electron flow/motion
⇒ the extended [redacted] point in the direction of the external magnetic field
⇒ the [redacted] points in the direction of resulting force

S = tips.

When a charged particle enters a magnetic field at 90° to the field, the particle experiences a force which is perpendicular to its velocity. While the speed of the particle is not effected, the direction of the particle's motion changes. In fact, the **magnetic force acts as a centripetal force** resulting in **uniform circular motion**.



×'s represent a magnetic field (B) acting into the page

$$F_m = F_c$$

$$q v_{\perp} |\vec{B}| = m a_c$$

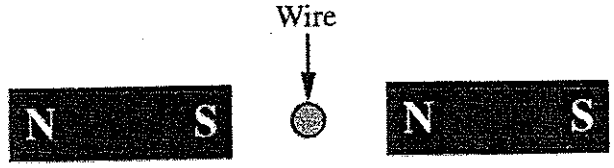
$$q v_{\perp} |\vec{B}| = m \frac{v^2}{r}$$

$$r = \frac{m v}{q |\vec{B}|} \quad \text{or} \quad \frac{q}{m} = \frac{v}{r |\vec{B}|}$$

It is **essential** that you know how to derive this relationship.

Use the following information to answer the next question.

Cross-Section of a Wire Suspended in a Magnetic Field



A wire is placed between two permanent magnets. As shown in the diagram, it is positioned so that it is perpendicular to the magnetic field and to the page. The mass of the wire is 0.850 g. The length of the wire perpendicular in the magnetic field is 1.30 cm.

6 4 1 2

Numerical Response

11. When a current of 10.0 A is sent through the wire, there is sufficient magnetic force to keep the wire supported against gravity. The magnitude of the magnetic field, expressed in scientific notation, is **a.bc** $\times 10^{-d}$ T. The values of **a**, **b**, **c**, and **d** are ____, ____, ____ and ____.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

$F_m = F_g$

$B \cdot I \cdot L = m \cdot g$

$B \cdot 10 \cdot .013 = .00085(9.81)$

$B = .0641$

38. A current-carrying conductor experiences a force F in a perpendicular magnetic field. A second conductor has the same length, twice the mass, and one half of the current in the same magnetic field. The magnetic force on the second conductor is

A. $\frac{1}{4}F$

(B) $\frac{1}{2}F$

C. F

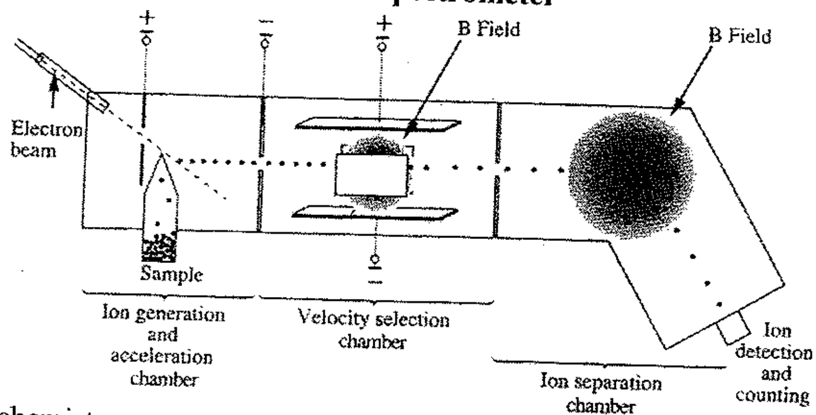
D. 2 F

$F_m = I \, l \cdot B$
$= \frac{1}{2} \cdot l \cdot B$
$= \frac{1}{2}F$

– mass has no relivance.

Use the following information to answer the next two questions.

Mass Spectrometer



A biochemist uses a mass spectrometer to identify the iron content in a water sample. In the ion generation chamber, the sample is bombarded with electrons to form Fe^{3+} ions. The ions from the sample are accelerated through a potential difference where they enter a velocity selection chamber.

The electric field strength in the velocity chamber is 2.50×10^4 N/C and the magnetic field strength in the velocity chamber is 1.25×10^{-2} T. Only particles with a certain velocity will pass through the perpendicular electric and magnetic fields of the velocity selector.

The ions then enter the ion separation chamber. The magnetic field strength in the ion separation chamber is 5.00×10^{-2} T and the radius of curvature is measured to be 7.74 m.

Numerical Response

12. The mass of the Fe^{3+} ion, expressed in scientific notation, is **ab.c** °.The values of **a**, **b** and **c** are ____, ____, and ____.

a.bc ×10⁻²⁶ kg

(Record all **three digits** of your answer in the numerical-response section on the answer sheet.)

$F_m = F_e$

$qvB = q \cdot |E|$

$v = \frac{|E|}{B} = \frac{2.5e^4}{1.25e^{-2}} = 2.0e^6$

$F_m = F_c$

$qvB = \frac{mv^2}{r}$

$\frac{qBr}{v} = m$

$\frac{(3\times1.6e^{-19})(5e^{-2})(7.74)}{2e^6} = m$

9.26×10^{-26}

Numerical Response

13. The ions were accelerated through a potential difference before they entered the velocity separation chamber. The potential difference, expressed in scientific notation, is $a.bc \times 10^d$ V. The values of *a, b, c,* and *d* are 3, 8, 7 and 5.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

$E_p = E_k$

$q\Delta V = \frac{1}{2}mv^2$

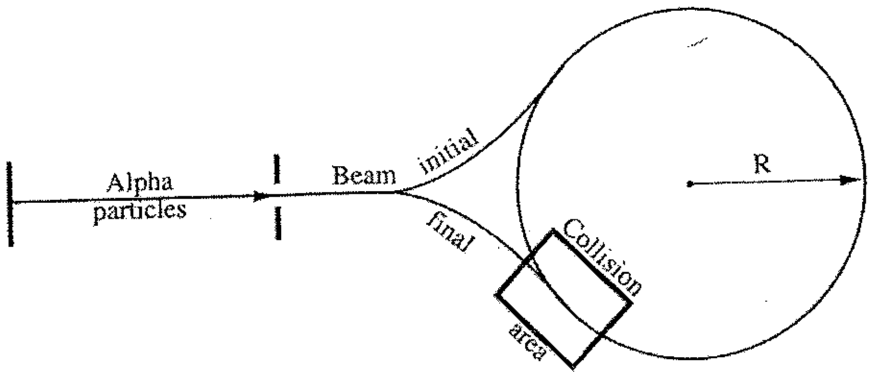
$= \frac{.5(9.29\times10^{-26})(2.0\times10^6)^2}{(3\times1.6e^{-19})}$

$= 3.87 \times 10^5$

Use the following information to answer the next question.

Zero Momentum Collisions

In order to have the maximum initial kinetic energy available for the creation of new particles, physicists design equipment to create head-on collisions with particles having the same magnitude of momentum. Thus the total momentum of the colliding particles is zero.



To bend the beam of alpha particles, external magnetic fields may be used.

39. To make an alpha particle that is moving at a speed of 8.07×10^6 m/s follow a path of radius 10.0 m, how strong must the magnetic field be?

A. 5.37×10^{-20} T
B. 1.68×10^{-2} T
C. 3.35×10^{-2} T
D. 8.07×10^{5} T

$F_m = F_c$

$qvB = \frac{mv^2}{r}$

$B = \frac{m \cdot v}{qr}$

$= \frac{6.65\times10^{-27} \cdot 8.07\times10^{6}}{3.2\times10^{-19} \cdot 10}$

$= 1.68\times10^{-2}$ T

40. A unit combination equivalent to the tesla is

A. $\frac{\text{kg}}{\text{A}\cdot\text{s}^2}$

B. $\frac{\text{N}\cdot\text{A}}{\text{m}}$

C. $\frac{\text{kg}\cdot\text{m}}{\text{A}\cdot\text{s}^2}$

D. $\frac{\text{A}}{\text{kg}}$

$F_m = qvB$

$\frac{F_m}{qv} = B$

$\frac{N}{C \cdot m/s} =$

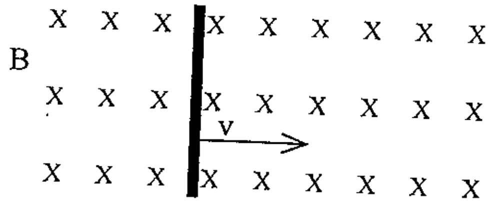
$\frac{\frac{kg \cdot m}{s^2}}{A \cdot m} = \frac{kg}{A \cdot s^2}$

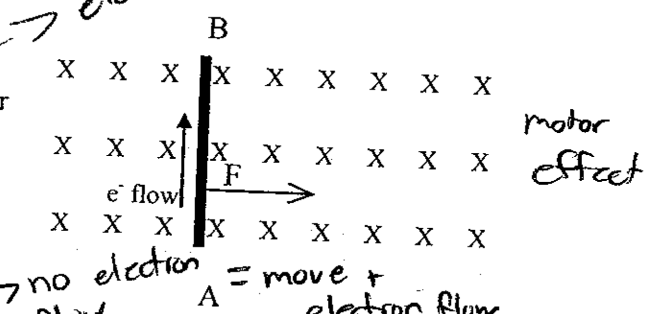
nerator Effect

The generator effect is based on **Faraday's Law of Electromagnetic Induction:**

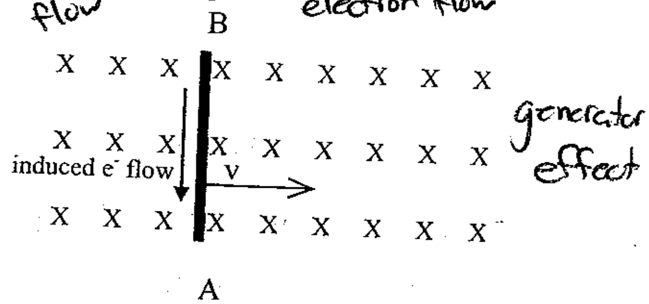
A changing magnetic field induces a potential difference in a conductor. Similarly, if a conductor is pulled through a magnetic field a potential difference is induced in the conductor.

Thus, when a conductor moves within a magnetic field a potential difference between the ends of the conductor is **induced.**





How does the **generator effect** compare with the **motor effect**? Consider the diagram to the right where a conductor is placed in a magnetic field. If electrons flow from A to B then Hand Rule #3 predicts that there will be a force on the wire directed to the right. This is the **motor effect – an electric current results is a force.**



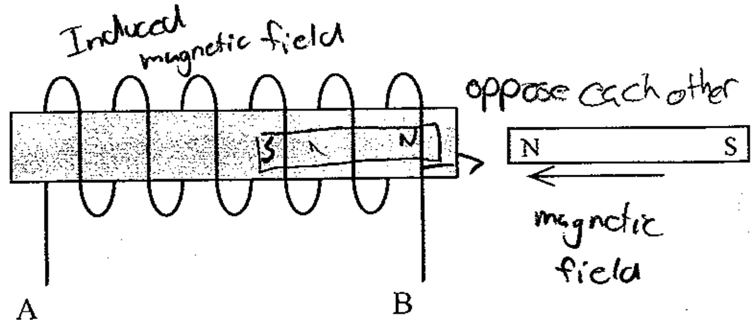
Now, what happens if we **disconnect the power source** from the wire and then **pull the wire** to the right through the magnetic field with speed v? The motion of the conductor through the magnetic field generates a flow of electrons in the conductor – the **generator effect.** Note that the induced electron flow is opposite to the motor effect. Faraday's Law addresses the induced current flow, but it does not predict the direction of current flow. Fortunately, Heinrich F. Lenz was investigating electrical induction about the same time as Faraday. In 1834, Lenz formulated a law for determining the direction of the induced current:

An induced current flows in such a direction that the induced magnetic field it creates opposes the action of the inducing magnetic field.

Lenz's law predicts results which are opposite to the motor effect if we move the wire instead. To account for this we can adjust Hand Rule #3. The **combined Hand Rule #3** integrates the motor effect and the generator effect. For the combined hand rule:
⇒ The *fingers* point in the direction of the external magnetic field.
⇒ The *thumb* points in the direction of what is **input**.
⇒ The *palm* points in the direction of what is **output**.
Thus, if current is being input, the current is the thumb and the resulting force is the palm. If the wire is being moved, the direction of motion is the thumb and the induced current/electron flow is the direction indicated by the palm.

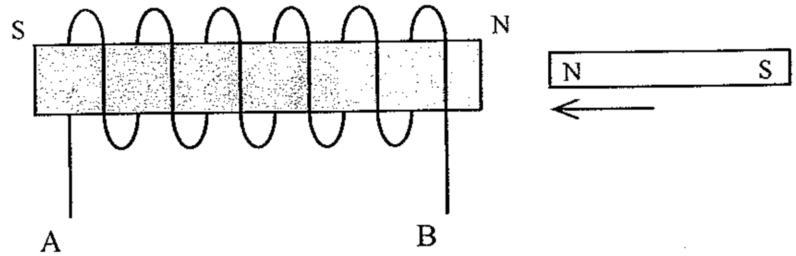
If you are confused about Lenz's law, perhaps an example may help.

Consider a magnet pushed into a coil of wire. Which way will the electrons flow?

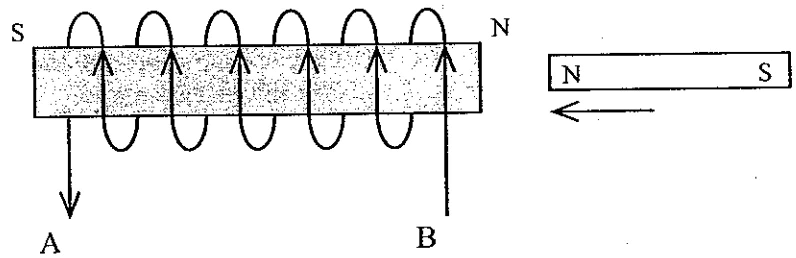


According to Faraday's law of induction, an electron flow will be induced in the coil wire by the motion of the bar magnet into the coil. However, as we saw earlier, an electron flow in a coil of wire induces a magnetic field (i.e. an electromagnet). Therefore, the induced electron flow in the coil will, in turn, produce a **new induced magnetic field** in the coil.

According to Lenz's law ~~**the induced magnetic field of the coil will oppose the motion of the original magnetic field**~~. Therefore, we indicate that a north pole will be induced on the right end of the solenoid since it will oppose (repel) the motion of the bar magnet.

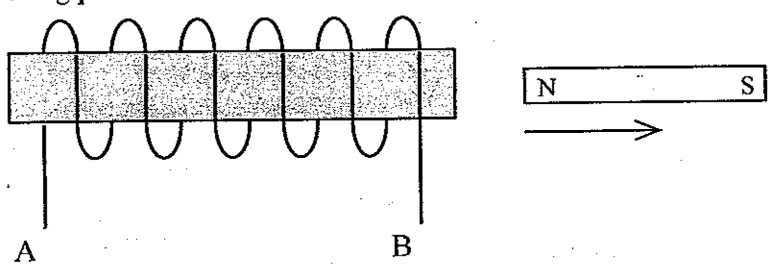


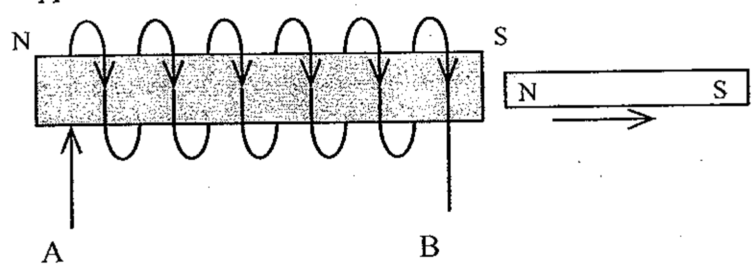
Using the hand rule for coils, the thumb points in the north direction while the fingers wrap around the coil in the direction of the electron flow. Therefore, **the electrons flow toward A and away from B**.



Now consider the situation when the magnet is being **pulled out** of a solenoid.

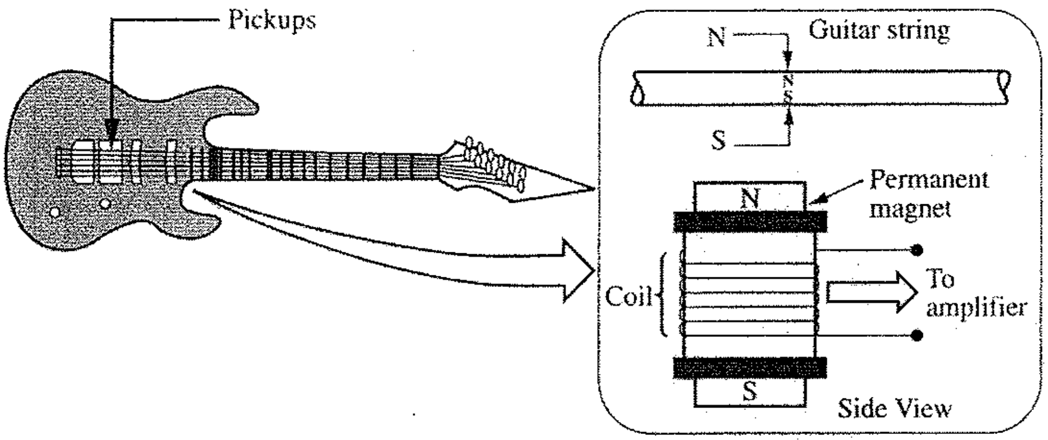
According to Lenz's law, the solenoid will have an induced magnetic field which opposes the motion of the inducing magnetic field (the motion of the bar magnet). Therefore, we indicate that a south pole will be induced on the right end of the solenoid – the solenoid is trying to pull or attract the magnet back. A north pole will be induced on the left. Using our hand rule, **the electrons flow toward B and away from A.**





Use the following information to answer the next question.

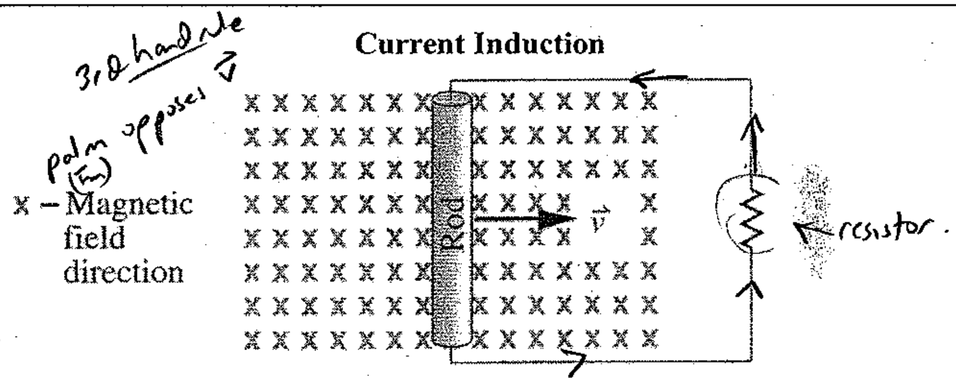
Almost all electric guitars use devices called electromagnetic pickups. A guitar string is composed of metal that becomes magnetized by a permanent magnet found below the string. A coil of wire surrounds the permanent magnet.



41. When the string is plucked, a small current is produced in the coil of wire because

A. a potential difference is produced in the string
B. there is a current in the string that can be amplified
C. there is a charge build up on the string
D. the string behaves as a magnet moving toward and away from the coil

Use the following information to answer the next question.



A conducting rod is moved through a perpendicular external magnetic field at a constant speed. The rod is attached to a circuit with a resistor.

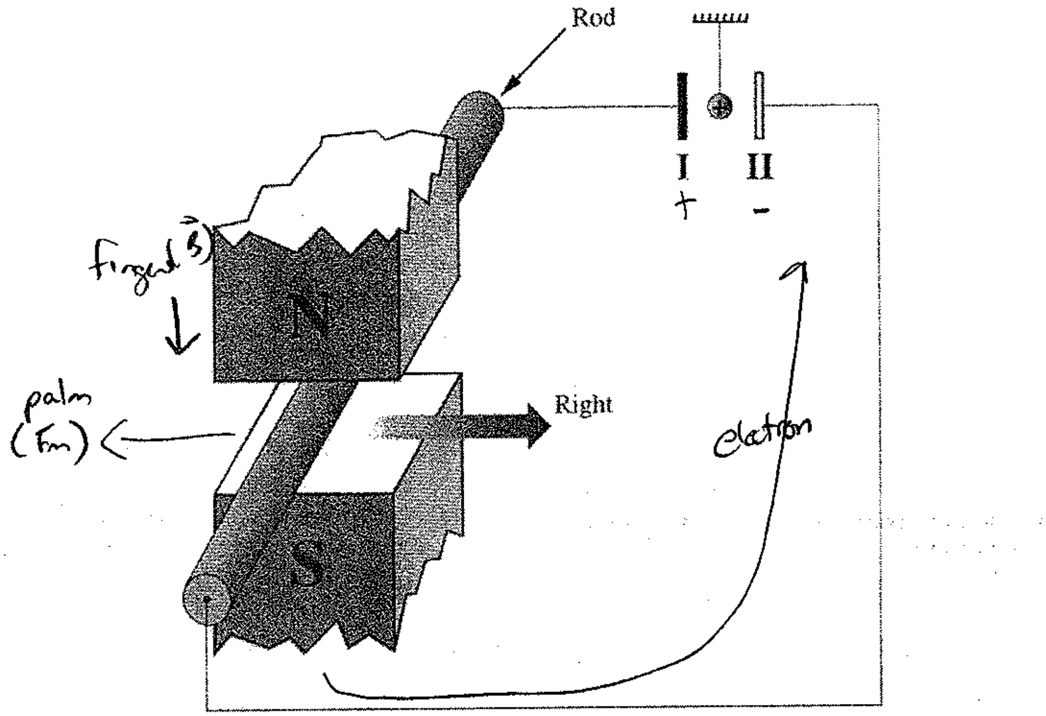
42. The direction of the flow of electrons induced by the rod's movement is

A. to the right
B. into the page
C. clockwise around the circuit
D. counter-clockwise around the circuit

fingers ($\vec{B}$) into page
palm (F_m) away from $\vec{v}$ (west)
thumb - direction of current

Use the following information to answer the next question.

A positively charged sphere is suspended by an insulating thread between two neutral parallel plates, I and II. The plates are connected by wire to a copper rod.



A student moves the copper rod to the right in an external magnetic field.

43. *As the student moves the copper rod, electrons flow toward plate __i__ and the charged sphere is observed to move toward plate __ii__ but does not come in contact with it.*

The statement above is completed by the information in row

Row	*i*	*ii*
A.	I	I
B.	I	II
C.	II	I
D.	II	II

Use the following information to answer the next question.

$V = B\,v\,l$
A wire of length l (with a speed v) passes perpendicularly through an external magnetic field B.

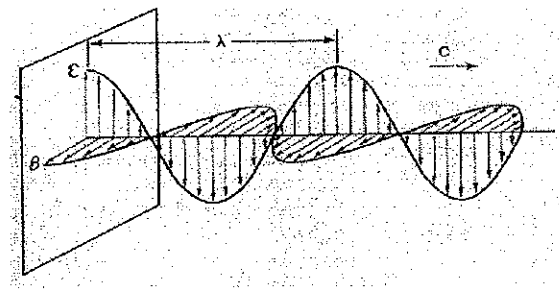
44. When the magnetic field strength is 0.235 T, the speed of the wire is 10.7 m/s and the length of the wire is 27.8 cm. The numerical value of V in SI base units is

A. 0.699
B. 2.51
C. 69.9
D. 251

$B_\perp \cdot v \cdot l$
$V = .235 \cdot 10.7 \cdot .278$
$= 0.699$ Volts

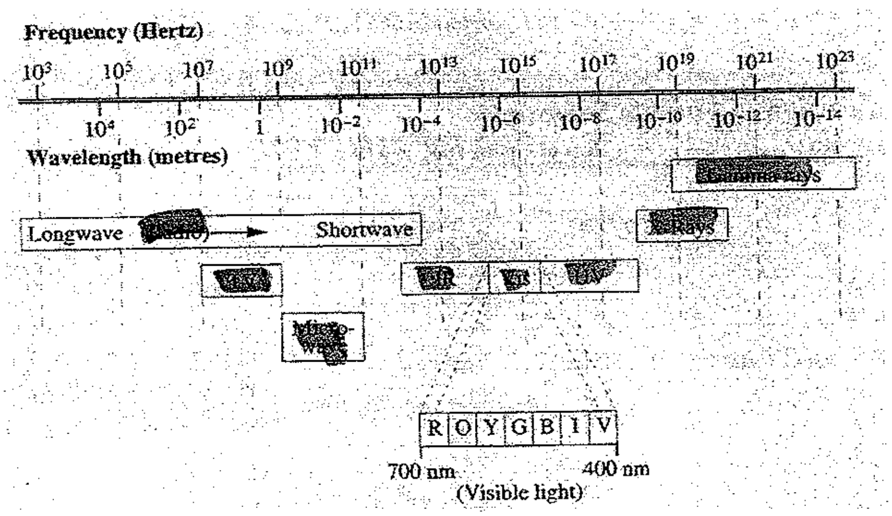
Electromagnetic Waves

Based on the work of Oersted, Faraday, Ampere and others, James Clerk Maxwell suggested that a **changing electric field induces a changing magnetic field** and a **changing magnetic field induces a changing electric field.** In other words, a changing electric field induces a changing magnetic field which induces a changing electric field which induces a changing magnetic field which induces a changing electric field which induces a changing magnetic field which induces a changing electric field which … Maxwell stated that energy could move through space by means of these fluctuating electric and magnetic fields. Energy moving through space suggests the existence of a wave. Maxwell had proposed a new kind of wave – an **electromagnetic wave.** The vibrating electric and magnetic fields are perpendicular to each other and to the direction of their propagation (motion). Further evaluation of these proposed waves revealed that in free space electromagnetic waves would move with a speed of 3.00×10^8 m/s – the **speed of light**. Based on this, he suggested that **light** is an **electromagnetic wave.**



Students are required to be able to demonstrate an understanding of the electromagnetic spectrum in terms of frequency, wavelength, energy and the natural and technological processes by which the different parts of the spectrum are produced. You are responsible for

⇒ knowing the various members of the electromagnetic spectrum and their approximate range of frequency or wavelength.
⇒ knowing how each type of radiation is produced and detected.
⇒ using the universal wave equation $c = f\lambda$ to calculate wavelengths and frequencies of any EMR.



The Electromagnetic Spectrum

Type of Radiation	Frequency Range (Hz)	Origin of Radiation	Applications or Effect of Radiation
low frequency AC	~60	weak radiation emitted from AC power lines	causes interference in radio reception when passing near high voltage transmission lines
radio, radar, TV	$10^4 - 10^{10}$	oscillations in electric circuits containing inductive and capacitive components	transmission of radio and TV communication signals; ship and aircraft navigation by radar; reception of radio waves from outer space by radio telescopes; control of satellites and space probes
microwaves	$10^9 - 10^{12}$	oscillating currents in special tubes and solid state devices	long range transmission of TV and other telecommunication information; cooking in microwave ovens
infrared radiation	$10^{11} - 4 \times 10^{14}$	transitions of outer electrons in atoms and molecules	causes the direct heating effect of the sun and other radiant heat sources; used for remote sensing and thermography
visible light	$4 \times 10^{14} - 8 \times 10^{14}$	higher energy transitions of outer electrons in atoms	radiation that can be detected by the human eye
ultraviolet radiation	$8 \times 10^{14} - 10^{17}$	even higher energy transitions of outer electrons in atoms	causes fluorescence in some materials; causes "tanning" of human skin; kills bacteria; and aids in the synthesis of vitamin D by the human body
x-rays	$10^{15} - 10^{20}$	transitions of inner electrons of atoms or the rapid deceleration of high energy free electrons	easily penetrates soft tissue but are absorbed by denser tissue, like bones and teeth, to produce X-ray images of internal body structures; also used for radiation therapy and non-destructive testing in industry
gamma (γ) rays	$10^{19} - 10^{24}$	spontaneous emission from nuclei of atoms; sudden deceleration of very high energy particles from accelerators	treatment for localized cancerous tumours
cosmic rays	$> 10^{24}$	bombardment of Earth's atmosphere by very high energy particles from outer space	

As an aid to help you remember the important parts of the electromagnetic spectrum you should memorize these three things:

1. Remember 700 nm (red) to 400 nm (violet).
2. ROYGBIV
3. The following table:

EM type	Frequency (Hz)
TV Radio	10^8
Microwave	10^{10}
Infra-Red	10^{12}
Visible	10^{14}
UV	10^{16}
X-rays	10^{18}
Gamma	10^{20}

Note that each frequency type goes up by a factor of 10^2 so you only have to memorize the order and the starting frequency. To find the equivalent wavelengths, use the universal wave equation. Recall that the **speed of all forms of light is 3.00×10^8 m/s** and that the **root cause of all EMR is accelerating charges**.

Use the following information to answer the next three questions.

> There is strong evidence that at least two planets are orbiting the pulsar neutron star PSRB 1257+12 in the constellation Virgo. The star emits radio waves that are detected with the 305 m diameter radio telescope in Puerto Rico. However, the orbiting planets' gravity causes the star to wobble in its rotation. The time it takes for the emitted radio waves to reach Earth varies.

45. One difference between radio waves and visible light is that radio waves

A. cannot be reflected
B. cannot travel through a vacuum
C. travel at a lower speed in a vacuum → all travel at speed of light.
D. have a longer wavelength than light

46. Radio waves from space longer than 1/10th the diameter of the radio telescope are undetectable on Earth's surface because of atmospheric interference. What is the approximate lower limit of the frequency of detectable waves?

A. 1.0×10^{-7} Hz
B. 32 Hz
C. 9.8×10^{6} Hz
D. 9.2×10^{9} Hz

$c = f\lambda$

$3e^8 = f \cdot 30.5$

$9.8 \times 10^6 \text{ Hz} = f$

Numerical Response

14. When the radio waves arrive 3.1×10^{-3} s sooner than predicted, the pulsar's orbiting planets have pulled the source of radiation closer to Earth. The change in distance, expressed in scientific notation, is $\boldsymbol{a.b} \times 10^{cd}$ m. The values of ***a, b, c,*** and ***d*** are __9__, __3__, __0__ and __5__.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

$v = \frac{d}{t}$

$3e^8 = \frac{d}{3.1e^{-3}}$

$= 9.3 \times 10^5$ m

Use the following information to answer the next question.

Sources of Electromagnetic Radiation

1 Movement of outer electrons to lower orbitals → releasing photons (visible)
2 Deceleration of high-speed electrons → x-rays
3 Decay of radioactive nuclei → gamma
4 Electrons oscillating in a circuit → radio

Numerical Response

15. Match each of the sources of electromagnetic radiation with the type of electromagnetic radiation it produces given below. Use each number only once.

Process:	3	1	2	4
Type:	Gamma rays	Visible light	X-rays	Radio waves

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

47. Which of the following sets of electromagnetic radiations is arranged in order of increasing photon frequency?

A. Gamma rays, ultraviolet radiation, radio waves
(B.) Radio waves, ultraviolet radiation, gamma rays
C. Gamma rays, radio waves, ultraviolet radiation
D. Radio waves, gamma rays, ultraviolet radiation

Light – Properties of Light

Basic properties of light

1. [redacted]. This is also referred to as **rectilinear propagation**. The evidence for this is that light creates shadows and it does not appear to bend around corners.

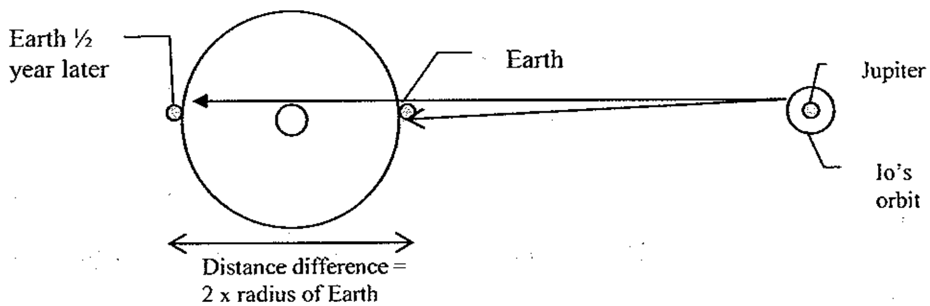
2. [redacted]. We can solve many problems by using straight lines to construct similar triangles and set up ratios of sides.

3. [redacted].

The speed of light

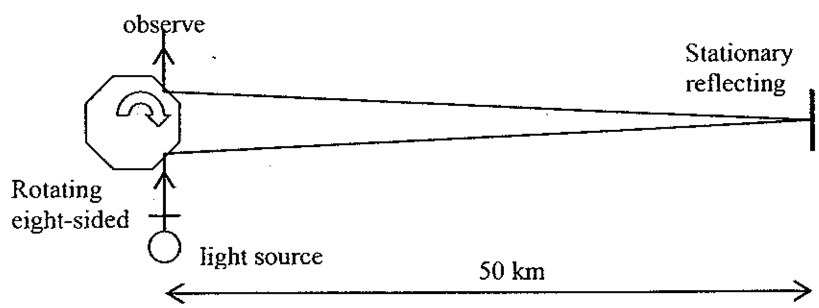
Galileo tried to measure the speed of light by measuring the time required for light to travel a known distance between two hilltops. He had an assistant stand on one hilltop and himself on the other and ordered the assistant to lift the shutter on his lantern when he saw a flash from Galileo's lantern. The time was so short that Galileo realised that the reaction time was far greater than the actual time for the light to move across the distance. He concluded that the speed of light was extremely fast, if not instantaneous.

The first successful determination of the speed of light began with an observation by the Danish astronomer Ole Römer (1644–1710). Römer noted that the period of one of Jupiter's moons (Io) varied slightly depending on the relative motion of the Earth and Jupiter. When the Earth was moving away from Jupiter the period was slightly longer, and when Earth moved toward Jupiter the period was slightly shorter. The Dutch scientist Christian Huygens (1629–1695) was intrigued by Römer's result. Huygens reasoned that if they measured when Io appeared from behind Jupiter for different positions of the Earth relative to Jupiter, there should be a time difference. Using the difference in distance and time



$$\text{speed of light} = \frac{\text{distance difference}}{\text{time difference}} = \frac{2 \times \text{radius of Earth orbit}}{\text{time difference}}$$

Alberta A. Michelson used a rotating mirror apparatus. Light from a source was directed at one face of a rotating eight-sided mirror. The reflected light travelled to a stationary mirror a large distance away and back again as shown. As the light travelled away and back, the eight-sided mirror rotated. If the rotating mirror was turning at just the right rate the returning beam of light would reflect from one of the mirror faces into a small telescope through which the observer looked. This only occurred if the mirror was turning at **exactly** the right rate. In this manner, the rotating mirror acted as a time piece. By knowing the frequency of rotation and the two way distance travelled by the light, one can calculate a very accurate value for the speed of light.



Example problem

In a Michelson-type experiment, a rotating eight-sided mirror was placed 50.0 km from the reflecting mirror as diagrammed below. The observer found that in order to observe the return light ray, the mirror had to rotate at 375 Hz. What is the speed of light calculated from this experiment?

a. Calculate the time for one revolution – T

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

$$T = \frac{1}{375\ \text{cycles/s}}$$

$$T = 2.667 \times 10^{-3}\,\text{s}$$

b. Calculate the time for the light to go to and return from the reflecting mirror – 1/8th T

$$\Delta t = \tfrac{1}{8}T = \tfrac{1}{8}(2.667 \times 10^{-3}\,\text{s})$$

$$\Delta t = 3.333 \times 10^{-4}\,\text{s}$$

c. Calculate the speed of light.

$$v = \frac{\Delta d}{\Delta t}$$

$$v = \frac{2 \times 50.0 \times 10^{3}\,\text{m}}{3.333 \times 10^{-4}\,\text{s}}$$

$$v = \mathbf{3.00 \times 10^{8}}\ \text{m/s}$$

The accepted value today for the speed of light in vacuum is

$c = 2.99792458 \times 10^8$ m/s which we usually round off to $c = 3.00 \times 10^8$ m/s.

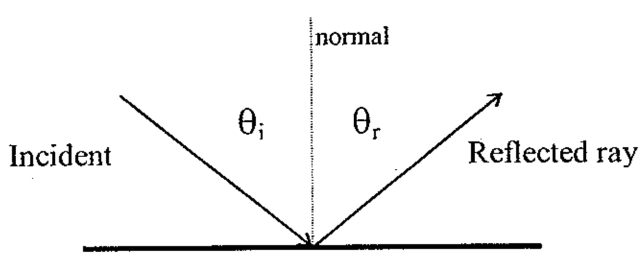
Light year – a distance

The vast majority of objects that we see in the night sky – stars, galaxies, nebulae – are very far away from us. In fact, for some objects it has taken light billions of years to reach us here on Earth. Therefore we are not seeing objects as they are, rather we are seeing them as they were many years ago when the light started toward us. These objects are so distant that it makes little sense to talk about them in terms of metres, kilometres or even billions of kilometres. A more convenient measure of distance for celestial objects is the **light year**. [redacted]r. (A light year is **not** a unit of time.)

Law of Reflection

The Laws of Reflection are:

[redacted]e angle of incidence (θ_i) equals the angle of reflection (θ_r). ($\theta_i = \theta_r$)
[redacted]θ_i and θ_r are always measured from the normal to the surface of reflection.
[redacted]The <u>incident ray</u>, <u>normal</u>, and <u>reflected ray</u> all lie in the same plane.



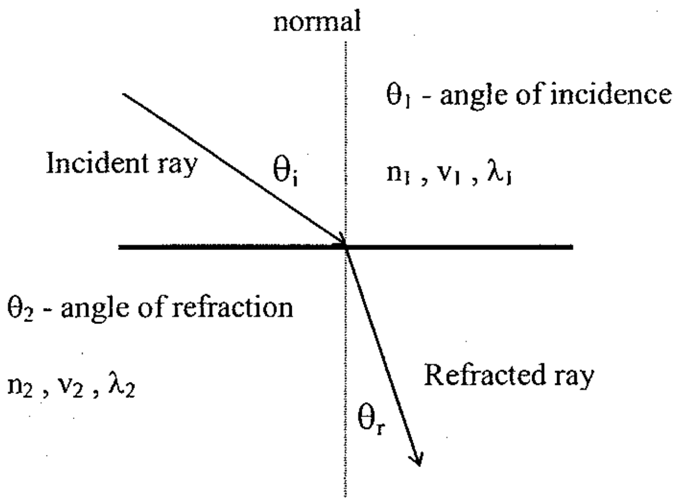
Index of refraction

The fastest that light can travel is in a vacuum ($c = 3.00 \times 10^8$ m/s). In other substances, the speed of light is always slower. The **index of refraction** is a ratio of the speed of light in vacuum with the speed of light in the medium:

$$\text{index of refraction (n)} = \frac{\text{speed in vacuum (c)}}{\text{speed in medium (v)}}$$

Law of Refraction - speed.

Refraction is the change in **speed, wavelength** and **direction** of light caused by a change in medium. For example, when light passes from air into water, the speed decreases, the wavelength decreases, and the light ray bends in toward the normal.



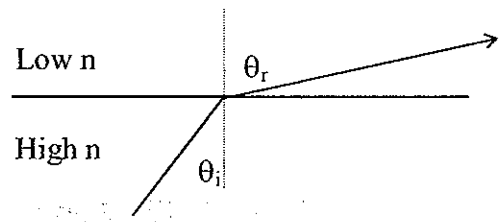
The Law of Refraction is:

$$\boxed{\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}}$$

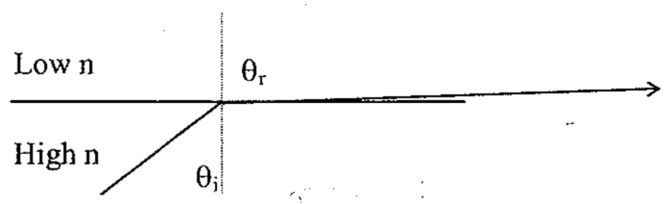
and we can use any pairing that we desire.

Total internal reflection

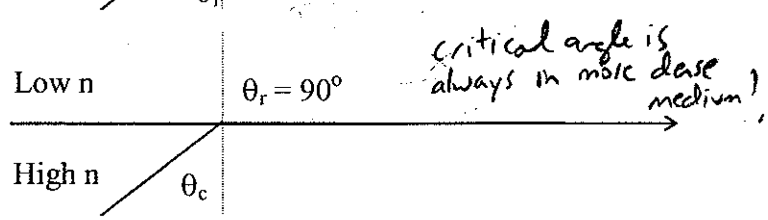
When a light ray passes from a more optically dense medium (high n, low v) to a less optically dense medium (low n, high v), the angle of refraction (θ_r) is greater than the angle of incidence (θ_i).



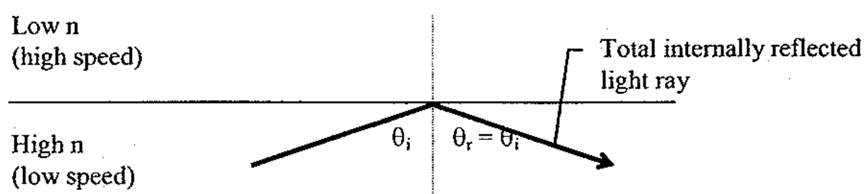
As the angle of incidence is increased, the angle of refraction becomes larger until finally θ_r approaches 90°.



At the angle of incidence called the **critical angle** (θ_c) the angle of refraction = 90°.



At angles beyond the critical angle, refraction can no longer occur – the result is total internal reflection, which obeys the law of reflection. In other words, at angles beyond the critical angle the boundary between the media acts as a mirror surface.

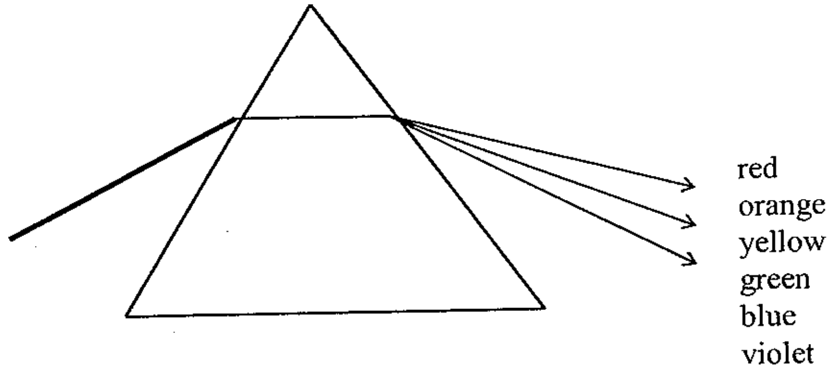


Note that total internal reflection occurs only when light travels from low to high speed media. It does not occur when light travels from high to low speed media.

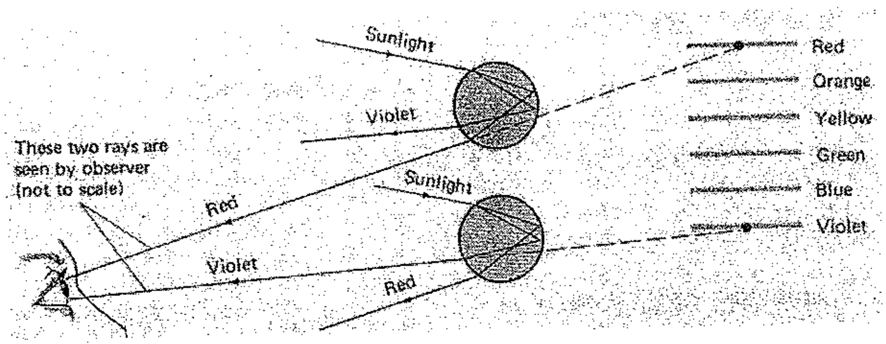
red refracts less
violet refracts most

Dispersion

The index of refraction (n) depends, to a small degree, on the frequency of the light. Normally this effect is so small that it does not result in a noticeable difference between different wavelengths (i.e. colours) of light, but for glass triangular prisms, the difference in the index of refraction for different colours of light results in a separation of the white light into its **spectrum of colours**. This separation of light into its colours is called **dispersion**.

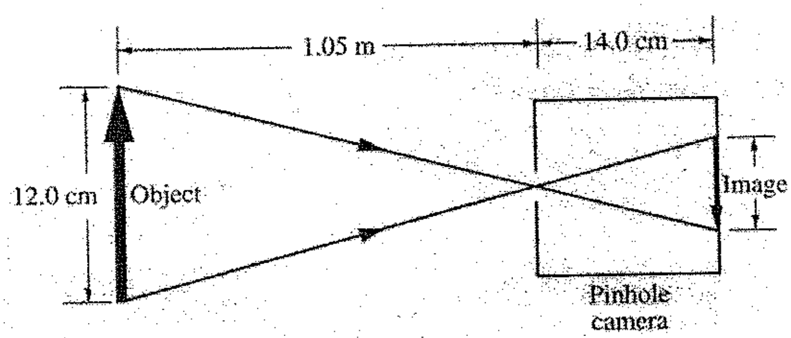


Rainbows are also a result of dispersion. Different wavelengths of light are refracted by different amounts by the water droplets. In this way, the different colours are separated resulting in a rainbow.



Use the following information to answer the next question.

Pinhole Camera



A pinhole camera produces an image of a 12.0 cm object.

1.60

Numerical Response

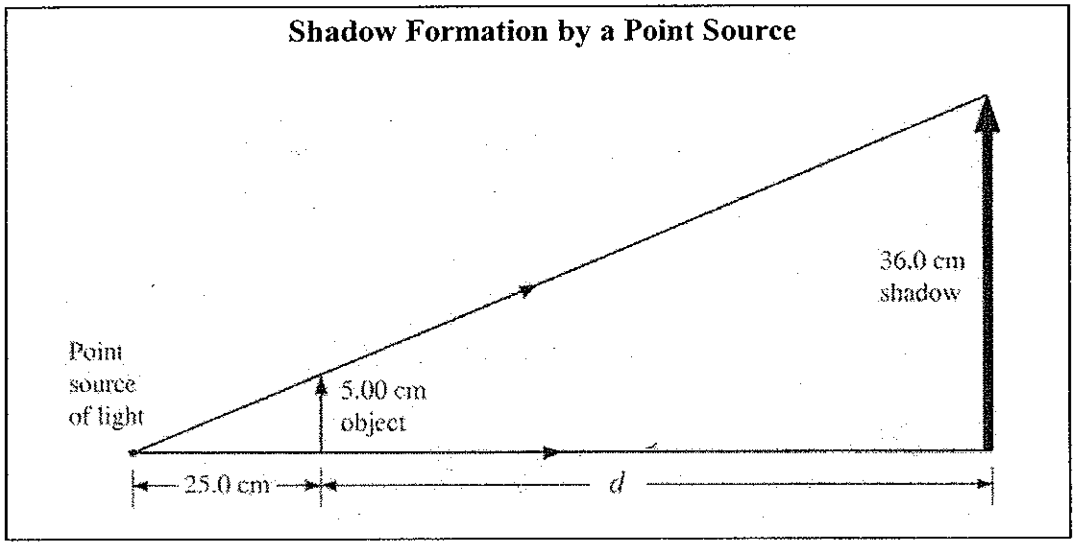
16. The object is 1.05 m from the front of the camera and the camera is 14.0 cm long. The height of the image on the back of the camera is _____ cm.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

$$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$\frac{105}{14\text{cm}} = \frac{12.0\text{cm}}{?} = 1.60\text{cm}$$

Use the following information to answer the next question.



48. An object 5.00 cm high is placed 25.0 cm from a point source of light. A shadow 36.0 cm high appears on a screen. At what distance, d, behind the object is the screen placed?

A. 7.20 cm

B. 32.2 cm

C. 155 cm

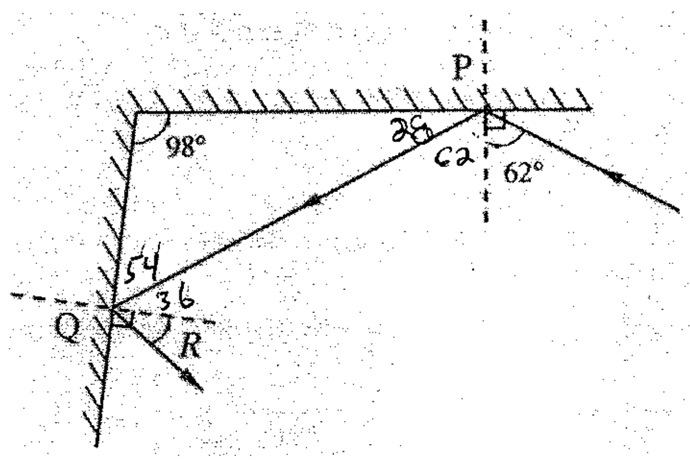
D. 180 cm

$\frac{5}{25} = \frac{36}{d+25}$

$d+25 = \frac{36 \cdot 25}{5}$

$d = 155$

Use the following information to answer the next question.



A light wave is reflected at P and again at Q. The diagram is not drawn to scale.

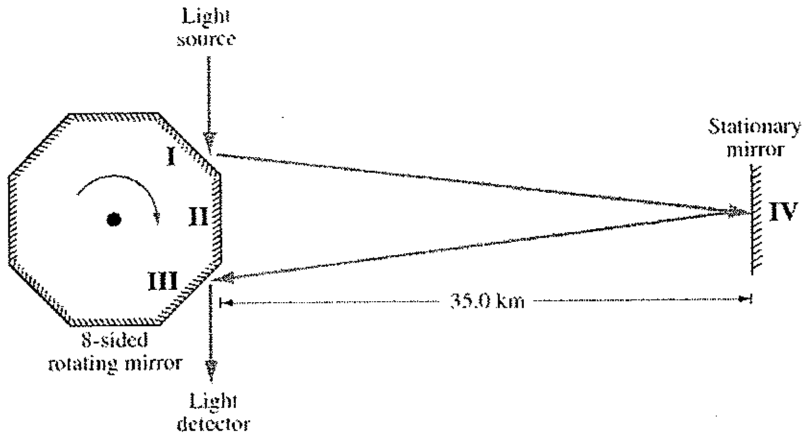
Numerical Response

17. The calculated value of angle R is 36 degrees.

(Record your **two-digit answer** in the numerical-response section on the answer sheet.)

Use the following information to answer the next question.

One accurate method to measure the speed of light is illustrated below. When the 8-sided mirror is stationary, light from the source reflects from surface I, travels to the stationary mirror, reflects from surface IV, travels back to the 8-sided mirror, reflects from surface III and is incident on the detector.

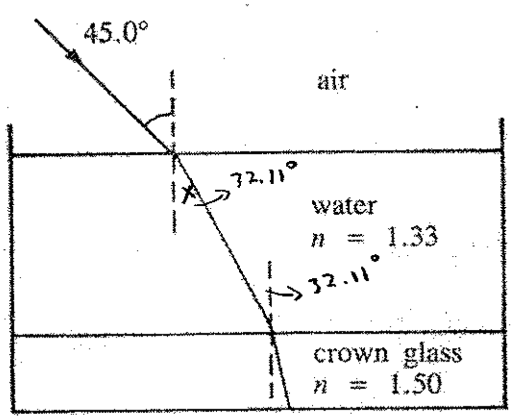


49. The minimum frequency at which the 8-sided mirror must rotate so that a pulse of light follows the path illustrated is

A. 5.36×10^{2} Hz
B. 1.07×10^{3} Hz
C. 4.29×10^{3} Hz
D. 3.43×10^{4} Hz

Use the following information to answer the next question.

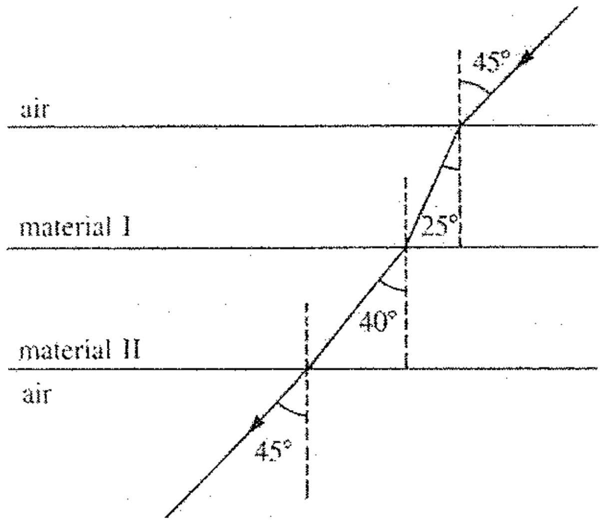
Refraction through a Water Layer



50. The angle of refraction in the crown glass is

A. 36.8°
B. 32.1°
C. 28.1°
D. 20.7°

Use the following information to answer the next question.



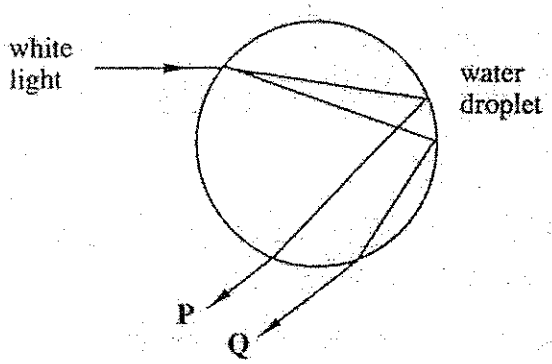
The larger the angle, the greater the Δ speed

A ray of light passes through two different transparent materials as shown. The faces of the materials are planar and parallel.

51. The speed of light in material I, compared to that in air and material II, is

A. less than in air and less than in material II
B. greater than in air but less than in material II
C. less than in air but greater than in material II
D. greater than in air and greater than in material II

Use the following information to answer the next question.



red refracts least

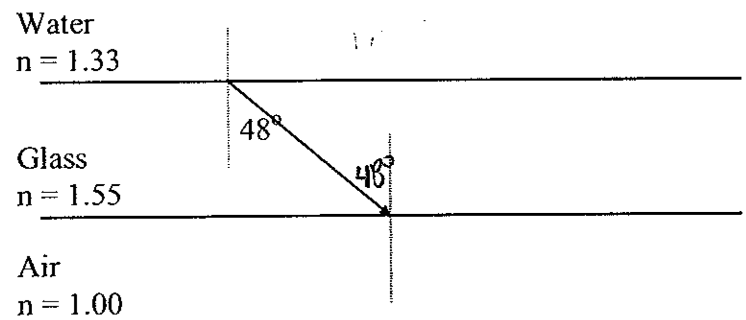
White light passes through a water droplet. P and Q are typical rays in the outer regions of the visible spectrum.

52. The color of ray P is most likely

A. red
B. blue
C. green
D. white

Use the following information to answer the next question.

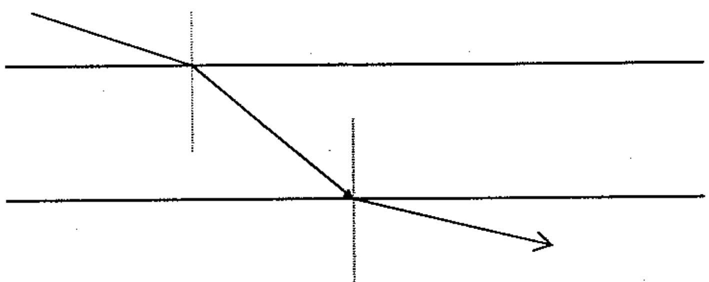
In the following ray diagram, the angle of refraction in glass is 48.0°.



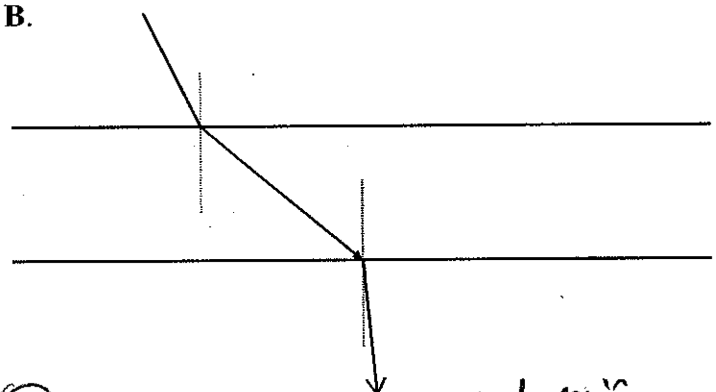
$\frac{n_1}{n_2} = \frac{\sin 2}{\sin 1}$

53. Which of the following diagrams indicates the remaining rays that correctly completes the ray diagram?

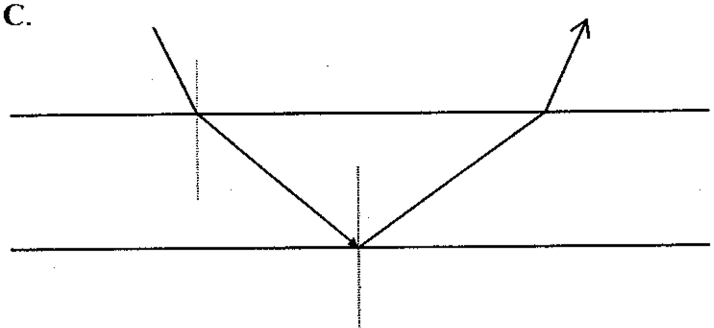
A.



B.

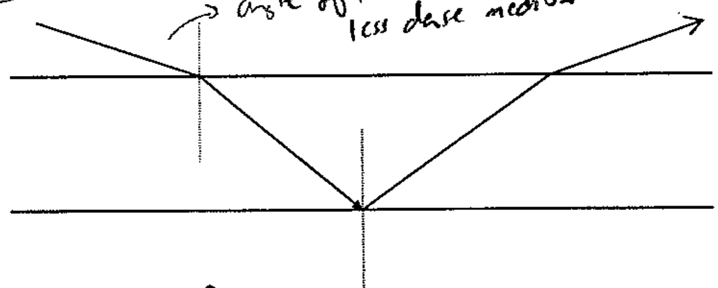


C.



D.

→ angle of incidence is larger in less dense medium



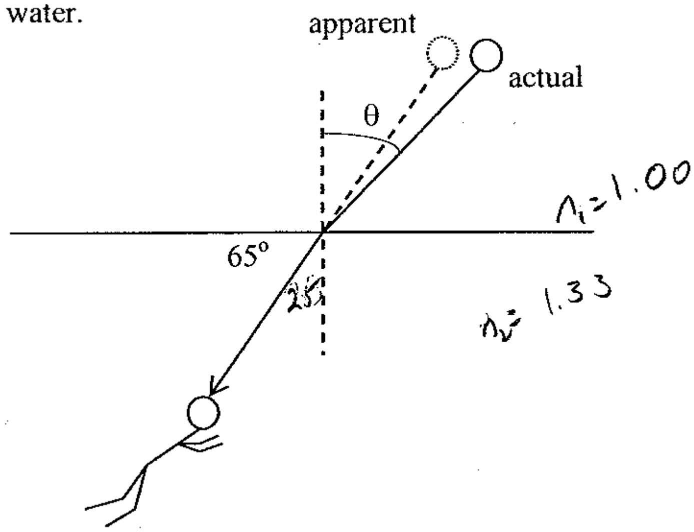
check critical angle from glass → air

$\frac{\sin \theta_1}{\sin 90} \quad \frac{1.00}{1.55}$

$\theta_1 = 40.1$ since angle is 48° internal reflection occurs.

Use the following information to answer the next question.

A scuba diver looks up and sees the sun's rays at an angle of 65° from the horizontal in the water.



(The diagram is not drawn to scale.)

54. Given that the refractive index for water is 1.33, the angle of incidence θ for the sunlight is

A. 25.0°

(B.) 34.2°

C. 43.0°

D. 55.8°

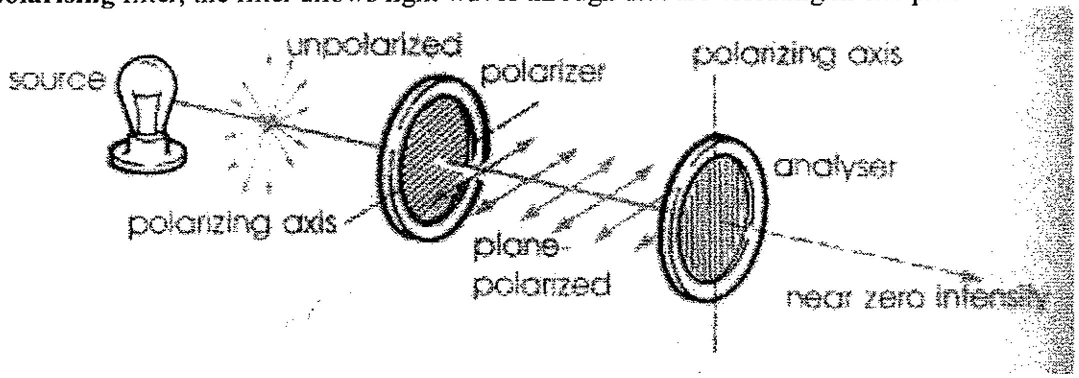
$$\frac{n_2}{n_1} = \frac{\sin \theta_1}{\sin \theta_2}$$

$$\frac{1.33}{1.00} = \frac{\sin \theta_1}{\sin 25}$$

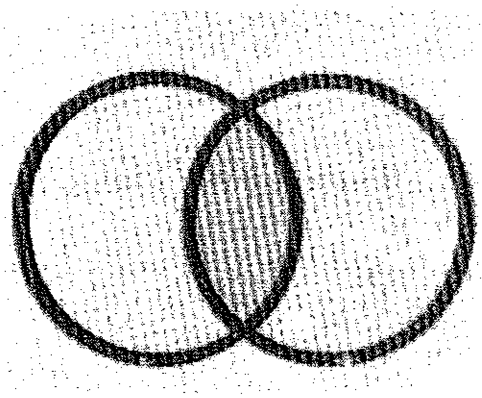
$$\theta_1 = 34.2^\circ$$

Polarisation

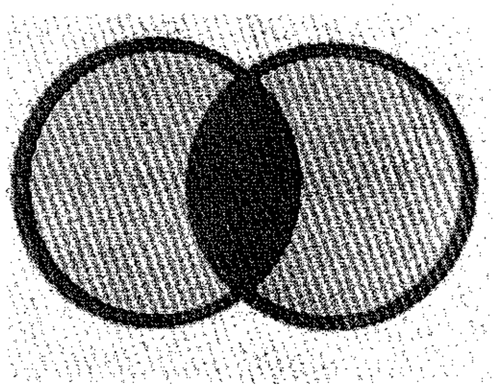
When light travels through space it vibrates in all planes. However, when light is passed through a **polarising** filter, the filter allows light waves through that are vibrating in one plane.



In the diagram above, un-polarised light passes through a polarising filter that is oriented to let horizontally vibrating light to pass through. If the horizontally polarised light next falls on a second filter that polarises light in the vertical plane, the light energy is almost completely absorbed.

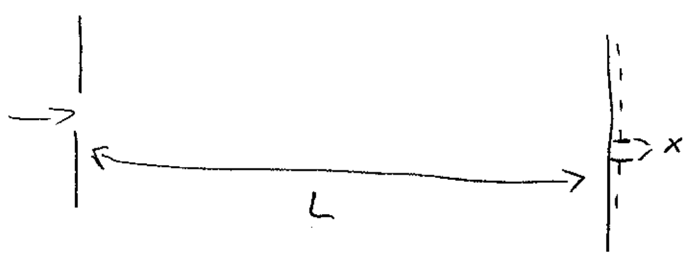


When polarising filter axis' are parallel, light passes through.



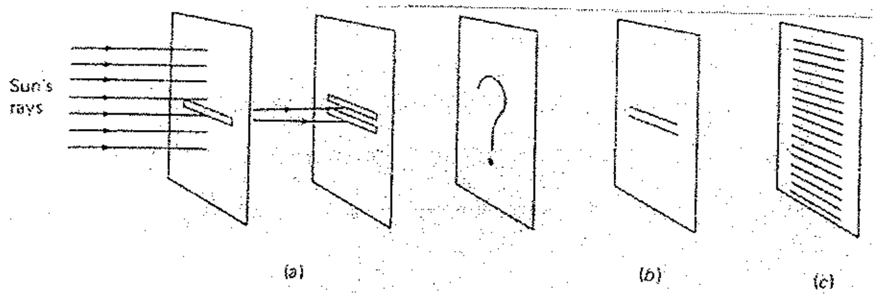
When polarising filter axis' are perpendicular, no light passes through.

Since only transverse waves can be polarised, we conclude that [redacted]



Interference of light

In 1801, a key experiment was performed by the brilliant Thomas Young (1773 – 1829). If light consisted of particles the result would be two bright fringes on the screen (screen b below), but the actual results were quite different. Instead of two bright fringes, there were a series of alternating bright and dark fringes (screen c below).



Young reasoned that he was seeing a [redacted] pattern caused by the [redacted] and [redacted] of light through each of the slits. Light diffracting through one of the slits interfered with the diffracted light from the other slit. When two waves meet they interfere with each other in an additive fashion. The waves combine either constructively or destructively depending on the situation. When crests meet crests and troughs meet troughs [redacted] occurs and these are called **antinodes** or **maxima** or [redacted]. When crests meet troughs, complete [redacted] occurs and these are called **nodes** or **minima** or [redacted]

The interference equations are:

over 10°, must use $\frac{d\sin\theta}{n} = \lambda$

$$\lambda = \frac{d\sin\theta}{n}$$

$$\lambda = \frac{d x_n}{nL} \; *$$

Where:
[redacted]– distance between slits
[redacted]– the distance from the slits to the viewing "screen" or area
[redacted]– the distance from the central maximum to the node or antinode of interest
[redacted]– the wavelength
[redacted] – the angle from the centre line to the node or antinode of interest

* [redacted]

Diffraction gratings

A large number of equally spaced parallel slits is called a **diffraction grating**. The spaces in between the lines serve as slits. Gratings containing more than 10 000 slits per centimetre are common today. A double slit apparatus produces an interference pattern where the fringes tend to be broad and relatively undefined. Diffraction gratings produce very sharp and well defined bright fringes.

The main difference in calculating variables between double slit problems and diffraction gratings is the way that slit separation is reported for diffraction gratings. Say, for example, a diffraction grating has 5000 lines/cm. To find the distance between the lines (d) requires two steps:

1. Calculate the number of lines per metre.

$$\frac{5000\,\text{lines}}{\text{cm}} \times \frac{100\,\text{cm}}{\text{m}} = 500\,000\frac{\text{lines}}{\text{m}}$$

2. To find d, simply invert $\frac{\text{lines}}{\text{m}}$ to obtain $\frac{\text{m}}{\text{line}}$.

$$d = \frac{1}{500000\frac{\text{lines}}{\text{m}}} = 2.0 \times 10^{-6}\,\text{m}$$

55. The idea that light is a transverse wave is supported by evidence that light

(A) can be polarized

B. bends toward the normal when slowing down

C. bends away from the normal when speeding up

D. waves will interfere with each other when passing through two narrow slits

Numerical Response

18. Light passing through a double slit of separation 3.0×10^{-5} m produces a first-order maximum 3.0 cm from the central maximum on a screen 1.5 m away. The frequency of the light, expressed in scientific notation, is $\boldsymbol{a.b} \times 10^{\boldsymbol{cd}}$ Hz. The values of ***a***, ***b***, ***c*** and ***d*** are ____, ____, ____, and ____.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

$\lambda = \frac{dx}{nl} = \frac{3e^{-5} \cdot .03}{1.5} = 6e^{-7}$

$v = f\lambda$

$f = \frac{v}{\lambda} = \frac{3e^{8}}{6e^{-7}} = 5.0 \times 10^{14}$ Hz

Numerical Response

19. Photons with energy of 3.10 eV are passed through a diffraction grating with 5.20×10^{5} lines/m. The grating is located 80.0 cm from a screen. The diffraction angle of the second-order image from the central bright line is _____°.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

$\lambda = \frac{d \sin\theta}{n}$

$4.0e^{-7} = \frac{5.2e^{5} \cdot \sin\theta}{.8}$

$124.6 = \sin\theta$

1. $E = h \cdot f$

$\frac{3.1}{4.14 \times 10^{-15}} = f$

$= 7.487 \times 10^{14}$

2. $v = f \cdot \lambda$

$\frac{v}{7.487} = \lambda$

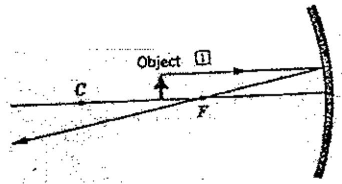
$4.0e^{-7} = \lambda$

Optics – mirrors and lenses

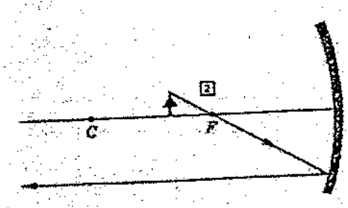
Ray diagrams

For **curved mirrors** there are <u>three</u> very useful rays which may be used to determine the position, orientation and nature of an image being formed. **The point where the three rays cross is the location of the image.**

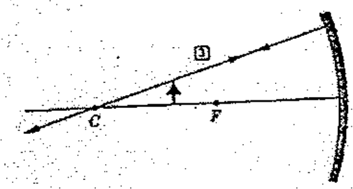
Ray 1 The incident ray which is parallel to the principal axis will reflect through (or away from) the focal point.



Ray 2 The incident ray through the focal point is reflected parallel to the principal axis.



Ray 3 The incident ray travels along a line that passes through the centre of curvature and reflects straight back.

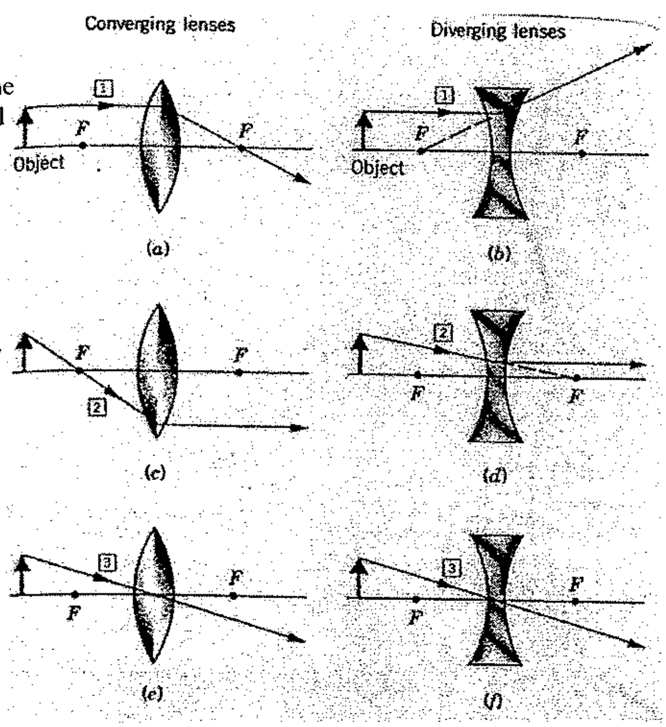


Similarly for **thin lenses**, there are three important rays:

ay [illegible] 'els from the object parallel to he pr[illegible]ipal axis. In passing through the ens, the ray is refracted to the *real* focal oint on the other side of the lens.

ay 2 travels through the virtual focal oint and is then refracted by the lens to merge parallel to the principal axis.

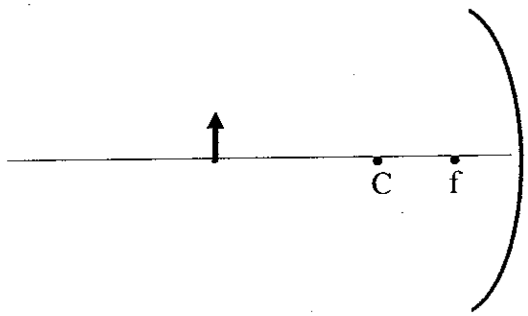
ay 3 travels through the centre of the hin lens straight through.



Ray 1 travels from the object parallel to the principal axis. In passing through the lens, the ray is refracted away from the *virtual* focal point of the lens.

Ray 2 travels from the object toward the *real* focal point. It then emerges parallel to the principal axis.

Ray 3 travels through the centre of the thin lens straight through.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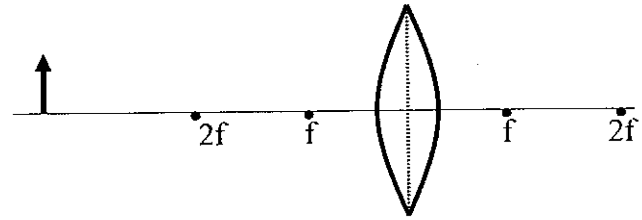
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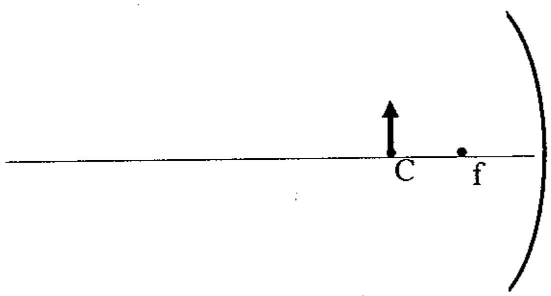
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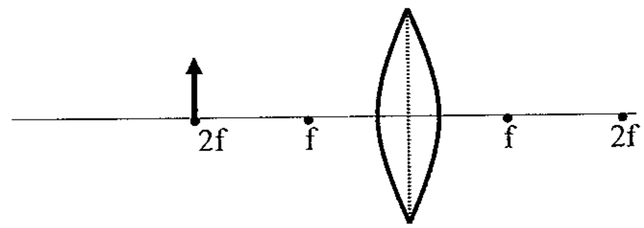
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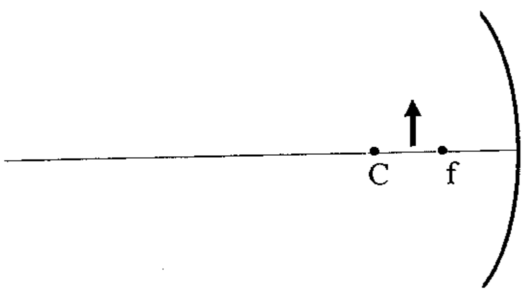
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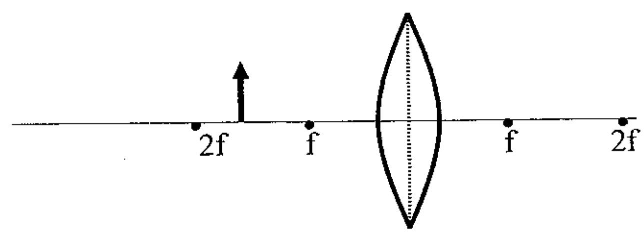
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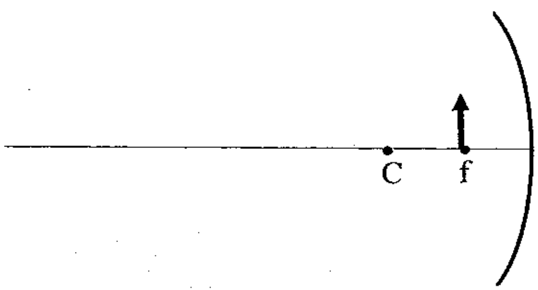
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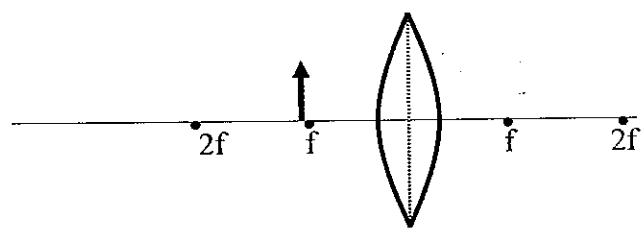
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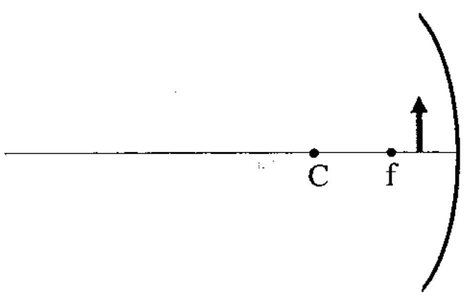
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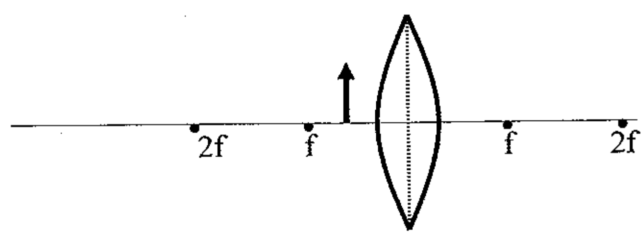
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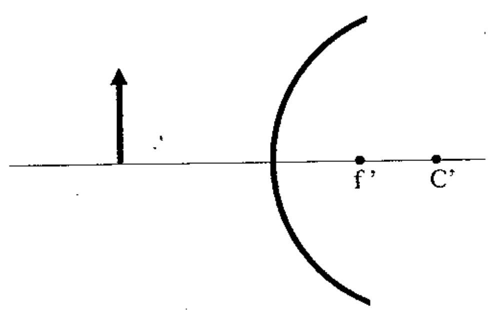
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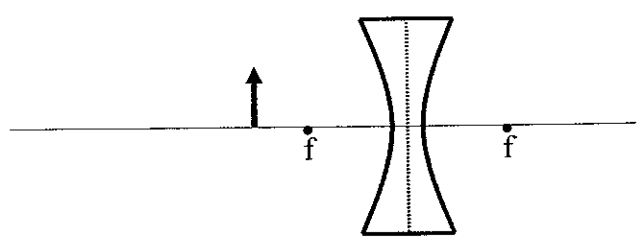
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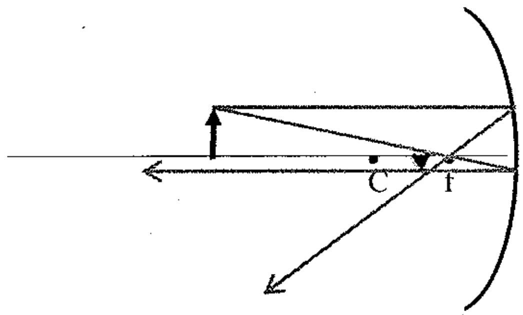
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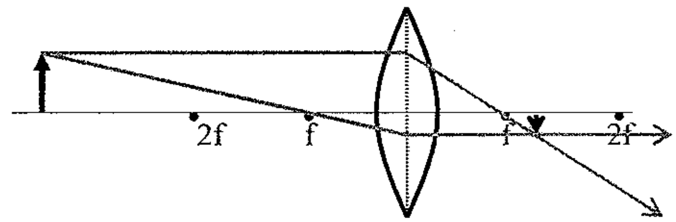
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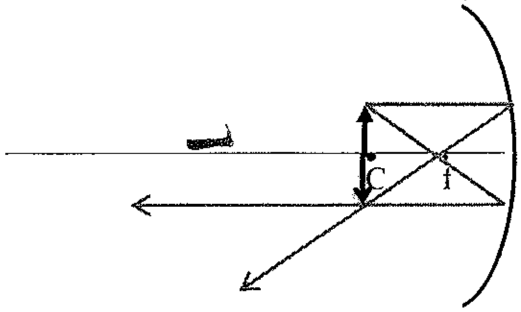
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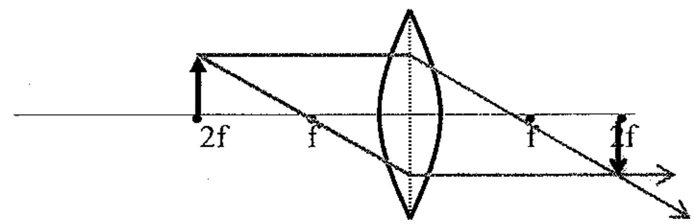
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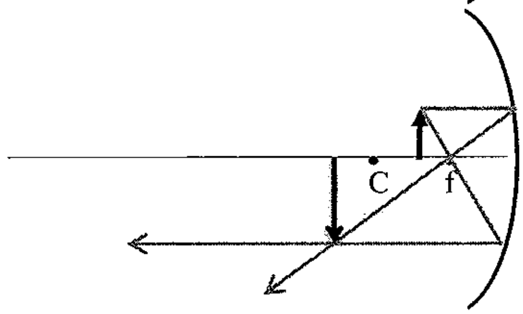
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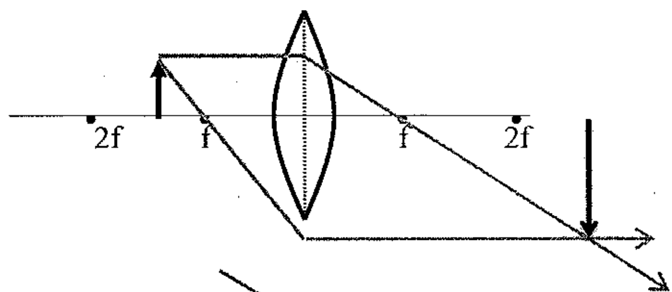
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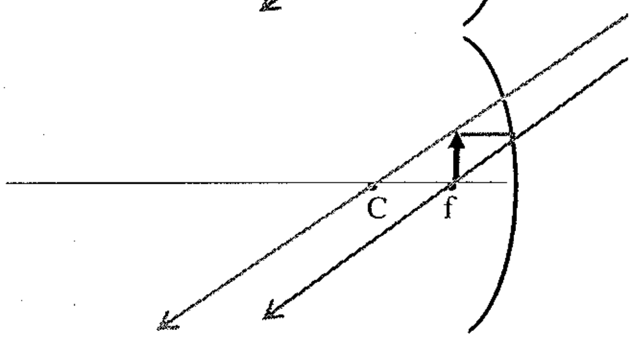
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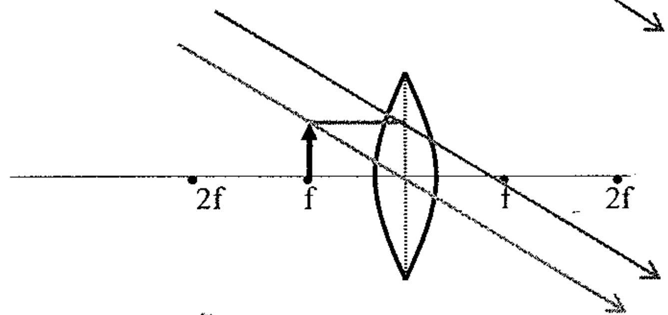
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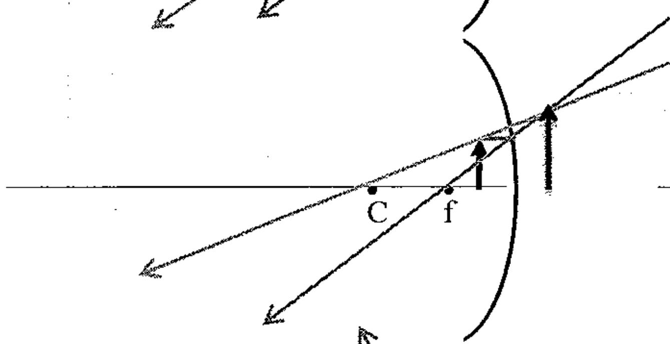
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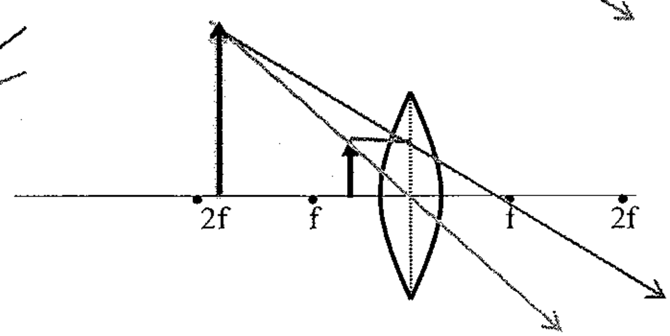
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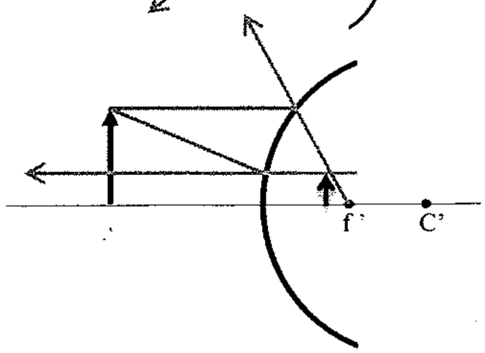
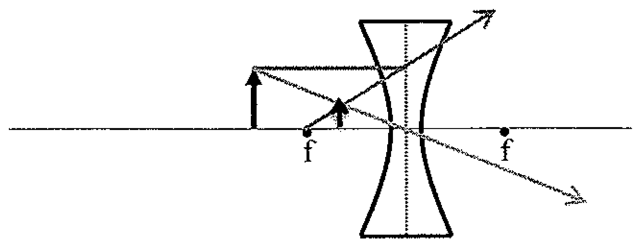

f'
C'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Mirror and lens equations

The equations used for calculating the position of an image from a lens are identical to the equations for mirrors.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$M = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

where

f	focal length (converging +, diverging –)
d_o	distance to the object
d_i	distance to the image (real +, virtual –)
h_o	height of object
h_i	height of image (real –, virtual +)
M	magnification: real, inverted (–) virtual, upright (+)

56. An object is viewed in a diverging mirror with a focal length of 10.0 cm. If the object is 2.00 cm tall and 15.0 cm from the mirror, then the image is

A. larger, real, and 30.0 cm from the mirror
B. larger, virtual, and 6.00 cm from the mirror
C. smaller, real, and 30.0 cm from the mirror
D. smaller, virtual, and 6.00 cm from the mirror

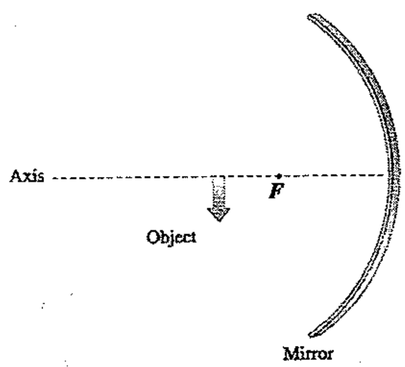
$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

$\frac{1}{-10} = \frac{1}{15} + \frac{1}{?}$

-6.0cm

Use the following information to answer the next question.

A concave mirror, its central axis, and an object are shown in the diagram below.



The distance from the object to the focal point is 2.40 cm and the focal length of the mirror is 4.30 cm.

57. The distance from the image to the mirror is

A. 0.0833 cm
B. 0.184 cm
C. 5.43 cm
D. 12.0 cm

$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

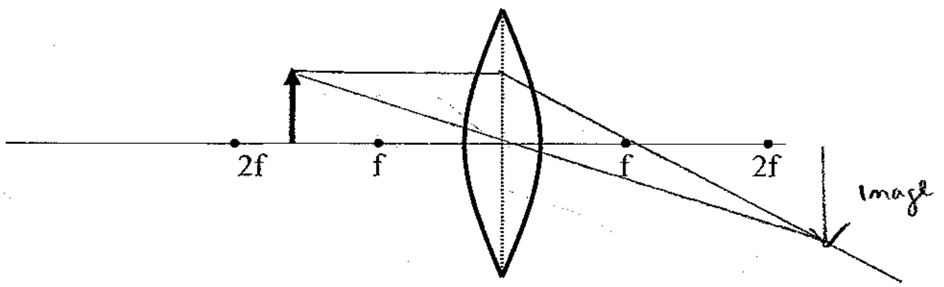
$\frac{1}{4.3} = \frac{1}{6.7} + \frac{1}{d_i}$

$12.0\text{cm} = d_i$

58. A lens with a focal length of 4.0 cm generates an inverted image which is five times as large as the object. What is the object distance?

A. + 4.8 cm
B. + 9.6 cm
C. + 19.2 cm
D. + 24.0 cm

Use the following information to answer the next question.

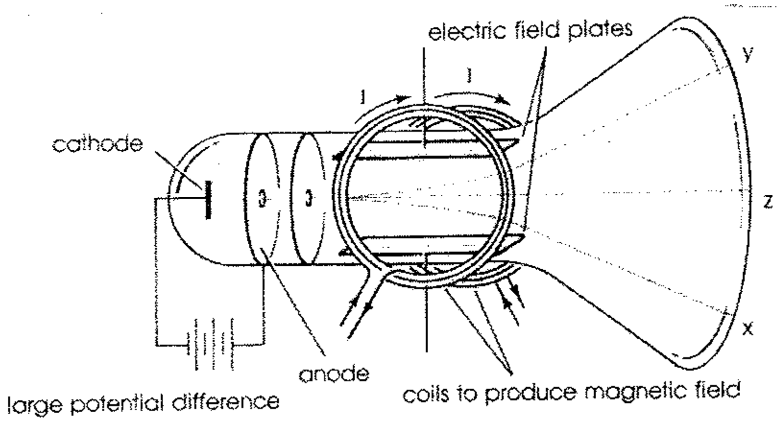


59. What will be the description of the image?

A. The image is erect and is located beyond 2F on the right side of the lens.
B. The image is inverted and is located beyond 2F on the right side of the lens.
C. The image is erect and is located between F and 2F on the right side of the lens.
D. The image is inverted and is located between F and 2F on the right side of the lens.

Cathode Rays

J. J. Thompson studied **cathode rays** using tubes similar to the one shown below.



Path **y** results when the electric field provided by the parallel plates is in operation.

Path **z** results when the electric and magnetic fields are adjusted so that their net effect on the cathode rays is zero.

Path **x** results when the particle goes through the magnetic field alone.

$$F_m = F_E$$

$$qv|\vec{B}| = q|\vec{E}|$$

$$v|\vec{B}| = |\vec{E}|$$

$$v = \frac{|\vec{E}|}{|\vec{B}|}$$

Thompson could vary the speed of the cathode rays by changing the potential difference between the cathode and anode. He could determine a precise value for the speed of the rays by balancing the electric and magnetic forces acting on the rays.

$$F_m = F_c$$

$$qv|\vec{B}| = ma_c$$

$$qv|\vec{B}| = m\frac{v^2}{r}$$

$$\frac{q}{m} = \frac{v}{|\vec{B}|r}$$

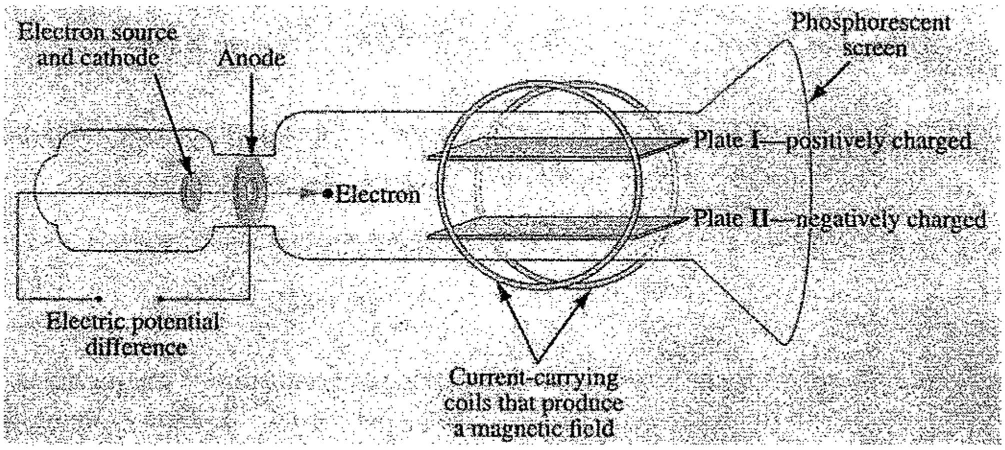
Once he had measured the speed of the cathode rays, he turned the electric field off and the cathode rays are then deflected into a circular path by the remaining magnetic field. He could measure the amount of deflection by taking distance measurements on the screen at the end of the tube.

At the time, Thompson did not know the charge or the mass of the cathode rays. Therefore, the best he could do was to measure the **charge to mass ratio** of the cathode ray. The charge to mass ratio for a cathode ray is 1.76×10^{11} C/kg. This large value indicates that a cathode ray (i.e. – **electron**) has a huge amount of charge relative to a very small mass.

Based on his work, Thompson proposed a new model of the atom, one where the atom was a sphere of positively charged fluid interspersed with electrons. This model is referred to as the "plumb pudding" model.

Use the following information to answer the next six questions.

An investigation is performed using the apparatus shown below. Electrons are accelerated from rest from the cathode by an electric potential difference. The cathode and anode are 2.00×10^{-2} cm apart. The electrons reach a speed of 2.10×10^{7} m/s as they pass through the hole in the anode.



Electrons then pass undeflected through a region in which there is both an electric and a magnetic field. The electric field is produced between plate I and plate II, which are 3.00 cm apart. The electric potential difference between the plates is 12.0 V. Two current-carrying coils produce a magnetic field that is perpendicular to the electric field.

Numerical Response

20. The electric potential difference between the cathode and the anode, expressed in scientific notation, is $\boldsymbol{a.bc} \times 10^{\boldsymbol{d}}$ V. The values of ***a***, ***b***, ***c***, and ***d*** are ____, ____, ____, and ____.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

$E_p = E_k$
$qV = \frac{1}{2}mv^2$
$1.6e^{-19} V = .5(9.11e^{-31})(2.1e^{7})^2$
$V = 1.26 \times 10^{3}$ V

60. The electric field between plate I and plate II is

A. 4.00×10^{2} V/m, toward plate I
(B.) 4.00×10^{2} V/m, toward plate II
C. 4.20×10^{4} V/m, toward plate I
D. 4.20×10^{4} V/m, toward plate II

$F_m = F_{el}$
$\frac{V}{d} = |E|$
$= \frac{12}{.03}$
$= 400 \frac{V}{m}$

Use the following additional information to answer the next question.

> The apparatus is then modified so that there is no electric field between plate I and plate II. The current flowing to the solenoids is adjusted so that the electrons are deflected in a circular path of radius 2.05 cm with a speed of 2.10×10^7 m/s.

$F_m = F_c$ $qB = \frac{mv^2}{r}$

Numerical Response

21. The magnitude of the magnetic field between the coils, expressed in scientific notation, is $a.bc \times 10^{-d}$ T. The values of a, b, c, and d are 5, 8, 3, and 3.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

5.83×10^{-3} T

61. Atoms in the phosphorescent screen absorb the energy of the cathode ray particles. They re-emit this energy in the form of photons of energy 4.11×10^{-19} J. One of these photons has a wavelength, expressed in scientific notation, of

A. 1.61×10^{-15} m

(B.) 4.84×10^{-7} m

C. 2.07×10^{6} m

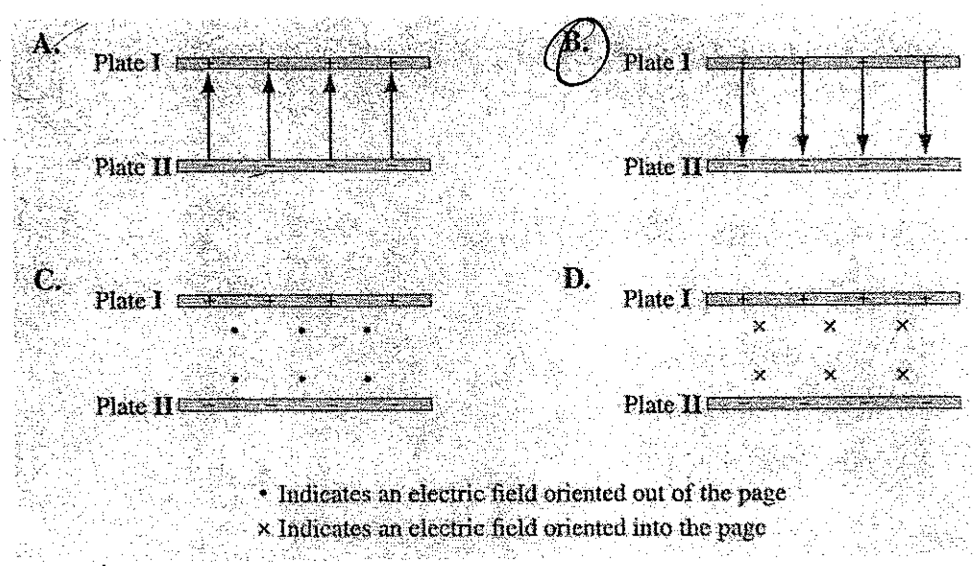
D. 6.20×10^{14} m

$E = \frac{hc}{\lambda}$

$4.11\times10^{-19} = \frac{6.63\times10^{-34} \cdot 3.0\times10^{8}}{x}$

$x = 4.84\times10^{-7}$ m

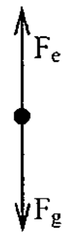
62. Which of the following diagrams shows the direction of the electric field between plate I and plate II?



63. Which of the following free-body diagrams shows the forces acting on an individual electron as it passes undeflected between plate I and plate II?

(A.)

B.



C.

D.

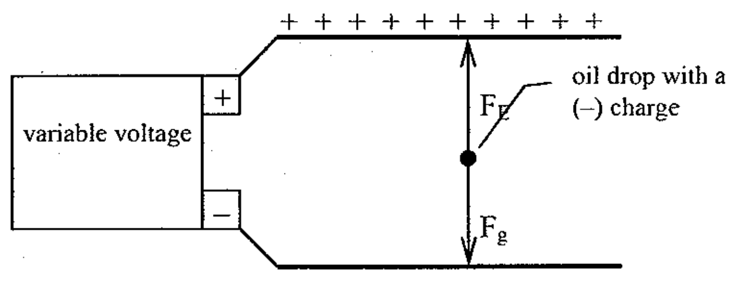
Undeflected
$F_e = F_m$

deflected
$F_m = F_c$

Force of gravity has no effect on e^-

Elementary Charge – Millikan's oil-drop experiment

Robert Millikan performed the oil-drop experiment to measure the **elementary charge**. A simplified version of Millikan's apparatus consisted of a small pair of horizontal parallel plates connected to a variable power supply.



$$F_E = F_g$$

$$q|\vec{E}| = mg$$

$$\frac{q\Delta V}{\Delta d} = mg$$

$$q = \frac{m g \Delta d}{\Delta V}$$

An individual droplet could be observed. If the droplet was brought to rest or at constant velocity, the gravitational and electric forces were balanced. The elementary charge (1.60×10^{-19} C) is the magnitude of the charge on the electron and on a proton.

↑F_E
↓F_g

64. In a Millikan experiment, a small sphere with a mass of 8.16×10^{-16} kg is suspended between plates that are 2.00 cm apart. This sphere is maintained at a potential difference of 1.00×10^{2} V. What is the charge on the small sphere?

A. 1.60×10^{-19} C

(B.) 1.60×10^{-18} C

C. 8.00×10^{-17} C

D. 4.00×10^{-12} C

$F_e = F_g$

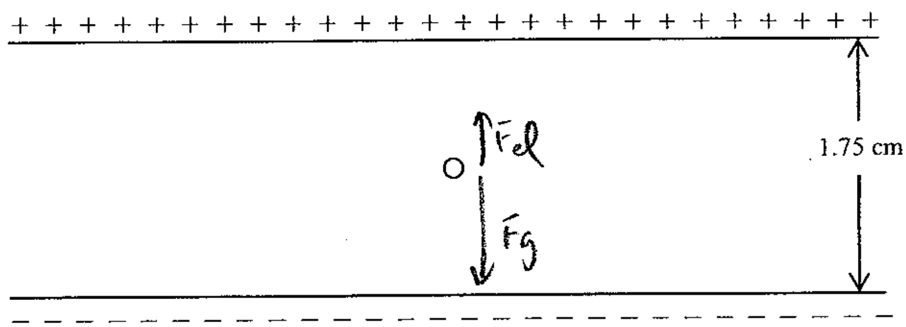
$q|E| = mg$

$q\,\frac{100}{0.02} = 8.16\times10^{-16} \times 9.81$

$q = 1.60\times10^{-18}$ C

Use the following information to answer the next question.

In a Millikan experiment, a small sphere with three excess electrons and a mass of 6.78×10^{-16} kg was injected between plates that are 1.75 cm apart.



The oil drop was observed to accelerate downward at 2.50 m/s^2.

Numerical Response

22. The potential difference between the plates, expressed in scientific notation, is $a.bc \times 10^{d}$ V. The values of a, b, c and d are _1_, _8_, _1_, and _2_.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

$F_{net} = F_g - F_e$

$ma = mg - q|E|$, $|E| = \frac{V}{d}$

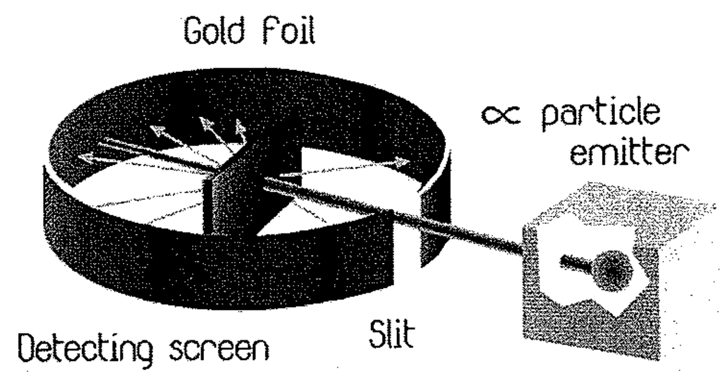
$6.78e^{-16} \cdot 2.5 = 6.78e^{-16} \cdot 9.81 - (3 \cdot 1.6e^{-19})\left(\frac{V}{.0175}\right)$

$= 180.64$

1.81×10^{2} V

Rutherford's Scattering Experiment

Ernest Rutherford, a student of J.J. Thompson, performed a set of experiments attempting to provide evidence that would support the Thompson model of the atom. These experiments involved directing alpha particles toward very thin foils of different metals. If the Thompson model of the atom was valid, these particles would pass through the foils with little or no change in direction.

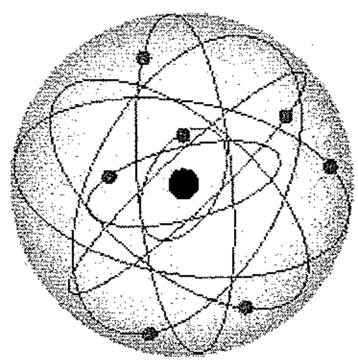


Rutherford was quite surprised to find that although most did show little or no deflection, a few of the particles showed large deflection angles and that some particles actually rebounded directly back from the foils. This could not be explained by the Thompson model. Rutherford realized that, in order to explain these observations, the positive charge and essentially all of the mass of the atom (recall that electrons have insignificant mass compared to even the lightest atom) must be concentrated in a very small volume of space. Rutherford called this concentration of mass and positive charge the **nucleus of the atom.**

In addition, the size of the nucleus was found to be on the order of 10^{-14} m, which is about 1/1000th of the diameter of the atom itself. This suggests two things:

- the electrons in the atom occupy the majority of the atom's volume.
- since the electrons have so little mass they must be even smaller than the nucleus and therefore the atom must be mostly **empty space**.

A **planetary model** of the atom was devised in 1911. The electrons had a certain speed and the electrostatic force between the nucleus and the electrons kept the electrons in orbit. However, this model seemed to have several major flaws:

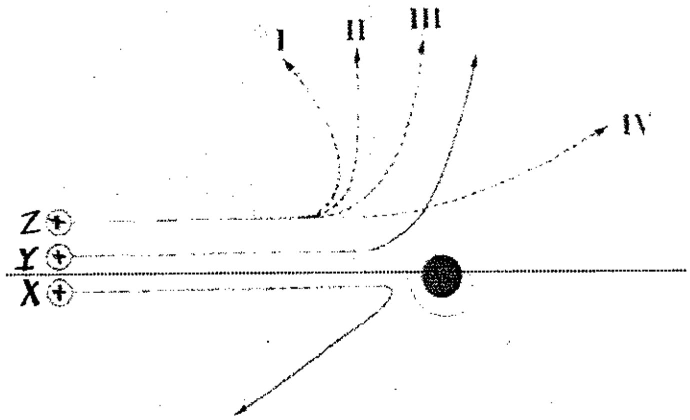


⇒ If electrons were in orbit with constant centripetal acceleration they would be continually emitting EM waves and thus would continually lose kinetic energy. The electrons should be spiralling into the nucleus.

⇒ How do all the positive charges stay in the nucleus?

Use the following information to answer the next question.

Scattering of Alpha Particles



Three alpha particles traveling at the same speed are deflected by the nucleus of a gold atom.

depends how close it is from nucleus

65. If particles X and Y are deflected as shown, particle Z will take path

A. I
B. II
C. III
(D) IV

$F_{el} \propto \frac{1}{R^2}$ farther distance less F_{el}

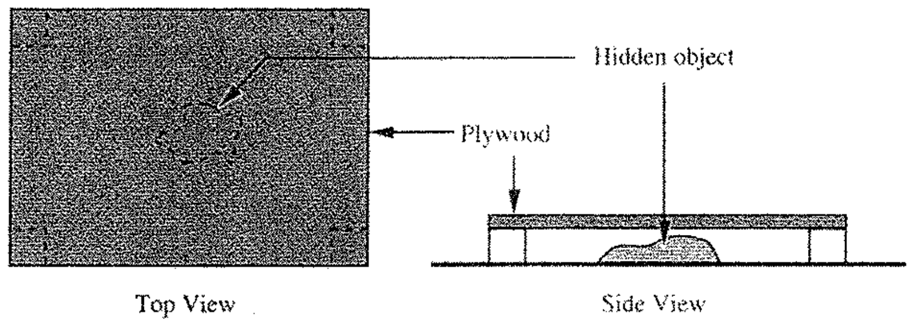
66. One of the reasons that Rutherford's planetary model of the atom has been modified is that observations of the atom do not support the theory of electrons orbiting the nucleus in a manner similar to planets orbiting a star. However, according to Maxwell's theory of electromagnetic radiation, such an orbiting electron should emit electromagnetic radiation because

A. the electron is travelling at uniform speed
(B) the electron is accelerating toward the nucleus
C. there is an electrostatic force of repulsion between the orbiting electrons
D. there is an alternating electromagnetic dipole as the electron switches sides of the nucleus

Key concepts - accelerating charges produces electromagnetic radiation.

Use the following information to answer the next question.

Students attempt to determine the nature of an object that is hidden beneath a sheet of plywood by rolling marbles under the plywood.



67. This exercise would help students appreciate the difficulties encountered by

A. Compton in his work on wave-particle theory
B. Einstein in his work on the photoelectric effect
C. Rutherford in his work on the nucleus of the atom
D. Thomson in his work on cathode rays

Blackbody Radiation

All objects or bodies absorb EM radiation and then re-emit at least some of that energy. A blackbody absorbs all frequencies of visible light but re-radiates only lower frequency (longer wavelength) radiation. The late 19th century theories and models could not predict what was actually observed. In 1900 Max **Planck** suggested a bold theory to explain this phenomenon. He suggested that the radiation emitted was due to the vibration of the molecules within the blackbody and that these molecules can vibrate with **only certain amounts of energy**. In other words, the vibration energies of the molecules were **quantized**. He then went on to suggest that the **energy emitted by these molecules was also quantized**. The energy emitted was not in continuous wave form but was emitted in discrete "bundles" that he referred to as **quanta or photons** of EM radiation.

The amount of energy carried by a quantum of EM radiation can be calculated using either

$$E_{photon} = hf$$

or $$E_{photon} = \frac{hc}{\lambda} \qquad E_{total} = n_{photons}E_{photon}$$

where h is Planck's constant

68. What is the energy of a photon that has a frequency of 2.5×10^{15} Hz?

A. 21 eV
B. 10 eV
C. 6.9 eV
D. 5.2 eV

> $E = h \cdot f$
> $= 4.14 \times 10^{-15} \cdot 2.5e^{15}$
> $= 10$ eV ✓

Numerical Response

23. The wavelength of a photon produced by an infrared laser is 4.23×10^{-5} m. The energy of a photon of infrared radiation, expressed in scientific notation, is $\boldsymbol{a.bc} \times 10^{-d}$ eV. The values of ***a, b, c*** and ***d*** are 2, 9, 4, and 2.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

$$E = \frac{hc}{\lambda}$$

$$= \frac{4.14\times10^{-15} \cdot 3e^{8}}{4.23\times10^{-5}} = .0294$$

Numerical Response

24. A 60 watt incandescent light bulb emits about 3.1 J of light energy every second. The average wavelength of the light is about 550 nm. The number of photons emitted per second by the bulb, expressed in scientific notation, is $\boldsymbol{a.b} \times 10^{\boldsymbol{cd}}$ photons. The values of ***a, b, c*** and ***d*** are ___, ___, ___, and ___.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

$$E_{photon} = \frac{hc}{\lambda}$$

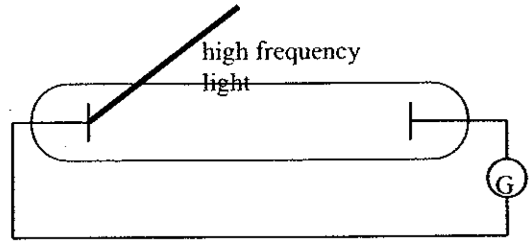
$$= \frac{4.14\times10^{-15} \cdot 3e^{8}}{550\times10^{-9}}$$

$$= 3.62\times10^{-14}\ \text{J}$$

$$n = \frac{E_{total}}{E_{photon}} \quad \frac{3.1\ \text{J}}{3.62\times10^{-14}\ \text{J/photon}}$$

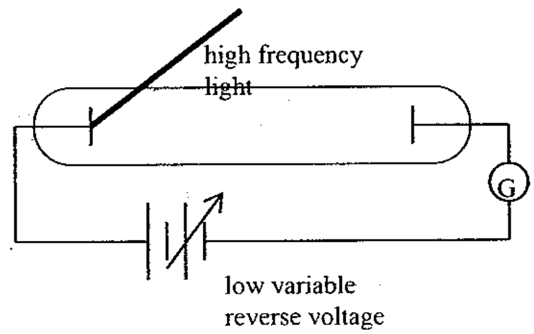
$$\doteq 8.6\times10^{18}\ \text{photons}$$

The Photoelectric Effect



In 1887, while studying Maxwell's theory of EM waves, Heinrich Hertz found that when high frequency light was shone onto a negatively charged electroscope the electroscope lost its charge. The light (photo) caused the electrons (electric) to be ejected from the electroscope. Using a cathode-ray tube Hertz experimented with the **photoelectric effect**.

He shone high frequency light onto one of the electrodes and electron flow, referred as a **photocurrent,** was **immediately** evident. Further, the light had to be at or above a certain **threshold frequency** (f_o) or no electrons flowed. The emitted electrons are referred to as **photoelectrons**. It was found that the magnitude of the photocurrent was directly proportional to the **intensity** (i.e. the number of photons per second) of the incident light.



Hertz found that he could reduce and eventually stop the flow of current by placing a **reverse potential difference** in the circuit as shown below. As he increased the reversing potential difference the photocurrent decreased until there is no current at all. The value of the reversing potential difference at this point of no current is called the **stopping voltage (V_{stop})**. With this arrangement Hertz could determine the maximum kinetic energy of the emitted photoelectrons.

$$E_{k\,max} = q_e V_{stop}$$

Hertz found that the kinetic energy of the electrons increased as the frequency of the incident light was increased.

f_o = threshold frequency

The properties of the photoelectric effect are:

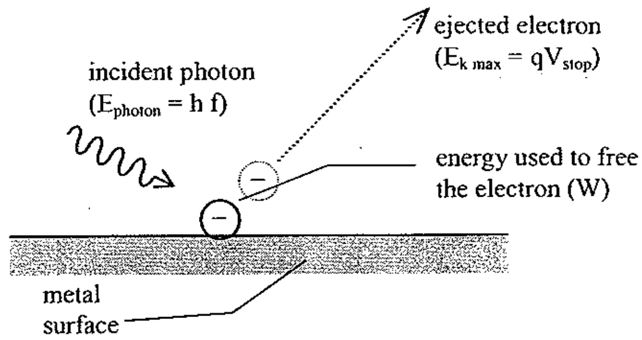
- when f is less than f_o no photocurrent flows
- when f is equal to or greater than f_o, current flows immediately
- the photocurrent is proportional to the intensity of the light
- E_k for the electrons increases as f of the incident light increases

These properties seem to be in conflict with EM wave theory. For example, in EM wave theory brighter light means more energy but the E_k of the photoelectrons does not vary with the intensity (brightness) of the incident light. While the photocurrent increased with brighter light, the kinetic energy of the electrons was not affected. In addition, according to EM wave theory the energy of a wave is related to its amplitude, but the energy of the electrons is related to the frequency of the incident light. EM wave theory could not explain the photoelectric effect.

EMR Wave theory ∴ brighter = more E_k but photoelectrons don't vary with higher brightness, standard energy

pe effect supports Particle model of emr.

No explanation for the photoelectric effect was found to be satisfactory until 1905 when Albert Einstein published an explanation that used Planck's concept of "light quanta" (photons). ~~Einstein suggested that a single photon of incident light would hit an electron on~~ the surface of a metal and ~~give all of its energy to that electron~~. Some energy, the **work function** (W), would be required to lift the electron off the metal. The remaining energy, if any, would be in the form of kinetic energy of that electron. Einstein applied the principle of conservation of energy and found that



$$E_{photon} = E_{k\ max} + W$$

→ amount used to release e⁻ from atom

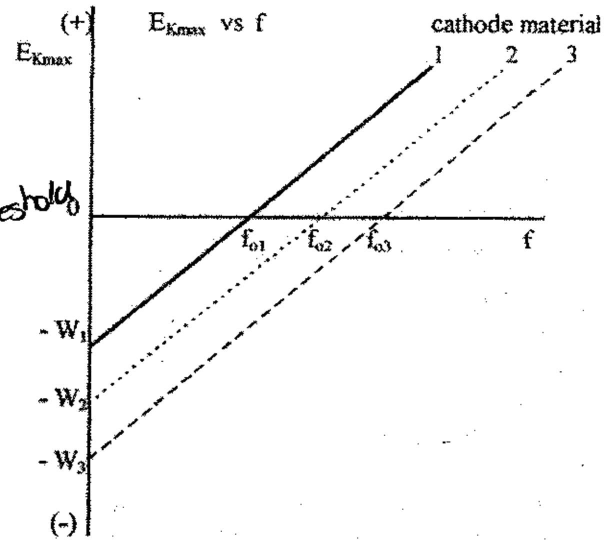
Using Planck's equation

$$hf = E_{k\ max} + W$$ (The work function may be calculated using $W = hf_o$)

A different arrangement of the equation yields

$$E_{k\ max} = hf - W$$ which is the equation for a line

$$y = mx + b$$



The graph of E_k vs f shows that:

⇒ f_o is the x-intercept
⇒ W is the y-intercept
⇒ the slope is Planck's constant.

69. If a metal with a threshold frequency of 1.1×10^{15} Hz is illuminated by light with a wavelength of 170 nm, then the maximum kinetic energy of the emitted photoelectrons will be

A. 4.4×10^{-19} J
B. 7.3×10^{-19} J
C. 1.2×10^{-18} J
D. 1.5×10^{-18} J

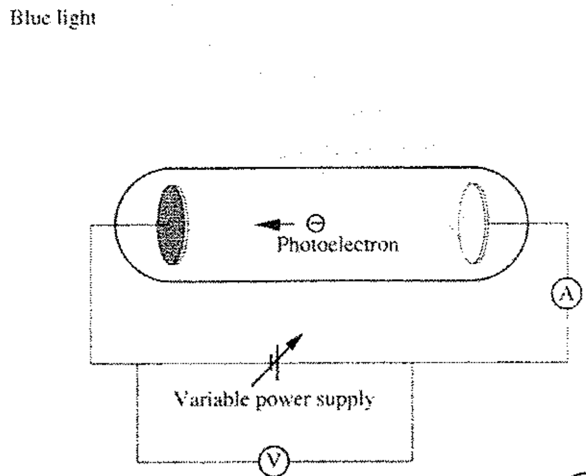
$E_{photon} = E_K + W$

$\frac{hc}{\lambda} = E_K + h \cdot f_0$

$\frac{6.63 \times 10^{-34} c}{170e^{-9}} = E_K + 6.63 \times 10^{-34} \cdot 1.1 \times 10^{15}$

Use the following information to answer the next question.

Photoelectric Effect



Photoelectrons are emitted when blue light of frequency 6.40×10^{14} Hz shines on a metal surface, as shown below. The stopping voltage is measured to be 1.25 V.

→ irrelivent

70. What is the maximum kinetic energy of the emitted photoelectrons?

A. 4.91×10^{-19} J
B. 2.91×10^{-19} J
C. 2.00×10^{-19} J
D. 1.28×10^{-19} J

$E_K = q \cdot V_{stop}$
$= 1.6e^{-19} \cdot 1.25$
$=$

---

71. A student performs a photoelectric experiment in which a photoelectric current is observed for all colours of visible light. The student wants to investigate what effect varying the intensity and colour of the incident light has on the photoelectric current and kinetic energy of the photoelectrons. If the brightness of the light is decreased and the colour is changed from yellow to blue, the photoelectric

→ lower intensity
→ higher frequency

A. current and photoelectron energy both decrease
B. current and photoelectron energy both increase
C. current decreases and the photoelectron energy increases
D. current increases and the photoelectron energy decreases

72. Copper has a work function of 4.46 eV. What is the maximum kinetic energy of the ejected electrons if the metal is illuminated by light with a wavelength of 450 nm?

A. 2.72×10^{-19} J
B. 4.42×10^{-19} J
C. 7.14×10^{-19} J
D. 0 J, because no electrons are ejected

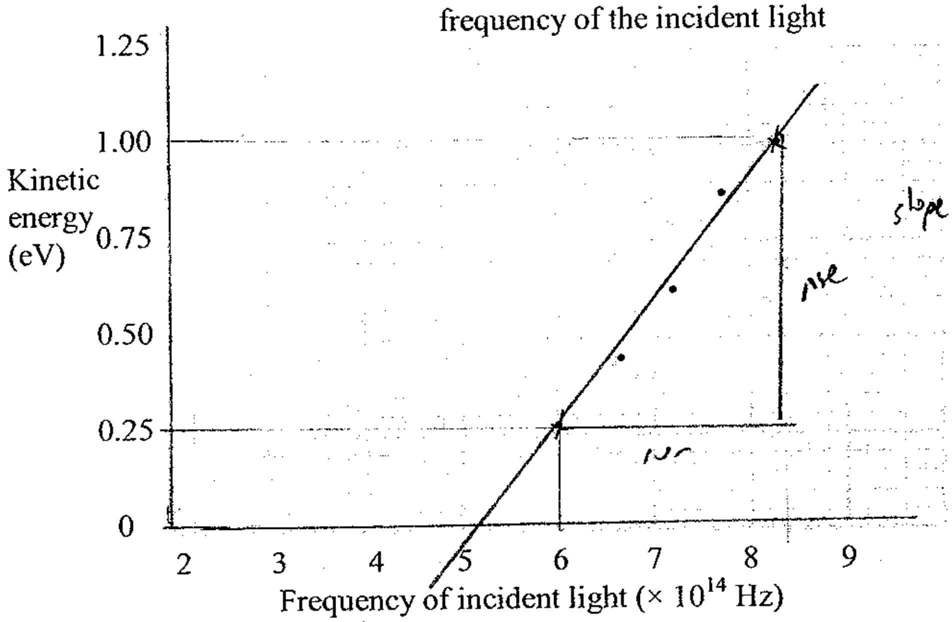
$E_{photon} = E_K + W$
$\frac{h \cdot c}{450e^{-9}} = \quad + 4.46$
$-1.7 eV = E_K$
less than 4.46 eV

* If Ek is neg it is not possible. (below fo)

Use the following information to answer the next question.

In a Millikan/Hertz photoelectric effect experiment, a student measured the maximum kinetic energy of the photoelectrons at several frequencies for sodium metal. She plotted the data as shown below.

Kinetic energy of photoelectrons as a function of the frequency of the incident light



slope = $\frac{.75 \text{ eV}}{2.2 \times 10^{14} \text{ Hz}}$

$= 3.4 \times 10^{-15}$ eV·s

Numerical Response

25. Using a line-of-best-fit, the threshold frequency, expressed in scientific notation, is ***a.b*** × 10^{14} Hz and the slope, expressed in scientific notation, is ***c.d*** × 10^{-15} eV·s. The values of ***a***, ***b***, ***c***, and ***d*** are ____, ____, ____, and ____.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

f_0 = x-intercept

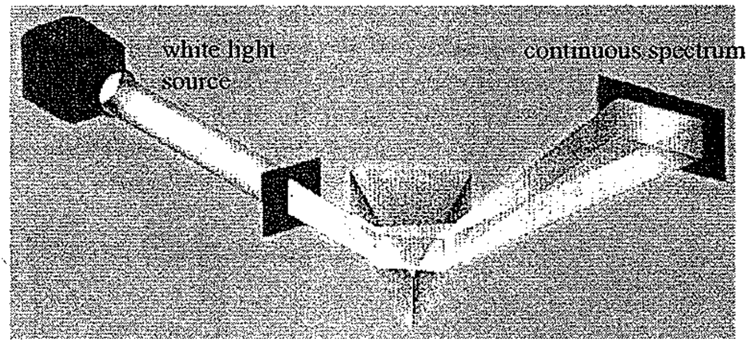
slope → h

Atomic Spectra

Spectra are the patterns produced when light is either **dispersed** through an equilateral glass prism or **split** apart by a diffraction grating – the light is separated into its colours.

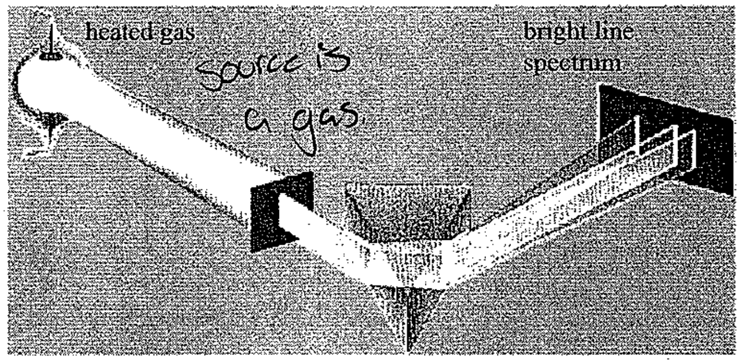
Continuous Spectrum

White light is produced from a white-hot solid, liquid or dense gas. For example, a light bulb has a tungsten filament which emits white light when electricity is used to heat the filament. The result is a **continuous spectrum**.



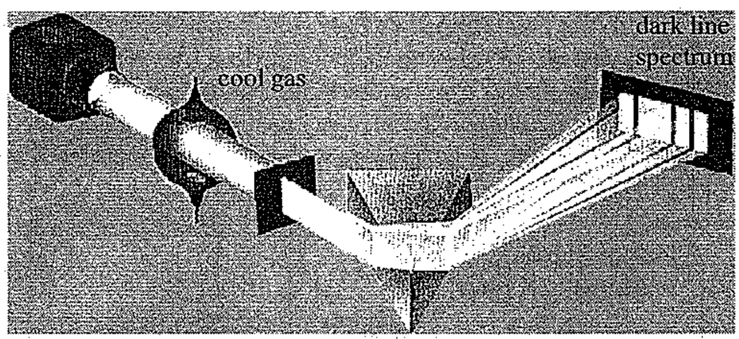
Emission or Bright-line spectra

Rarefied (thin density) gases will also emit light when heated to a high temperature or when electricity is passed through them. They produce a **bright line** or **emission spectra**. Each element and molecule has a unique spectrum.



gas. think these 2. (falls energy levels)

Dark Line or Absorption Spectra are produced by passing white light through a cold gas or vapour and then viewing the emerging light with a prism. The gas in the container absorbs a few discreet wavelengths or colours of light, while the majority of the light passes through the gas.



(goes to higher energy level)

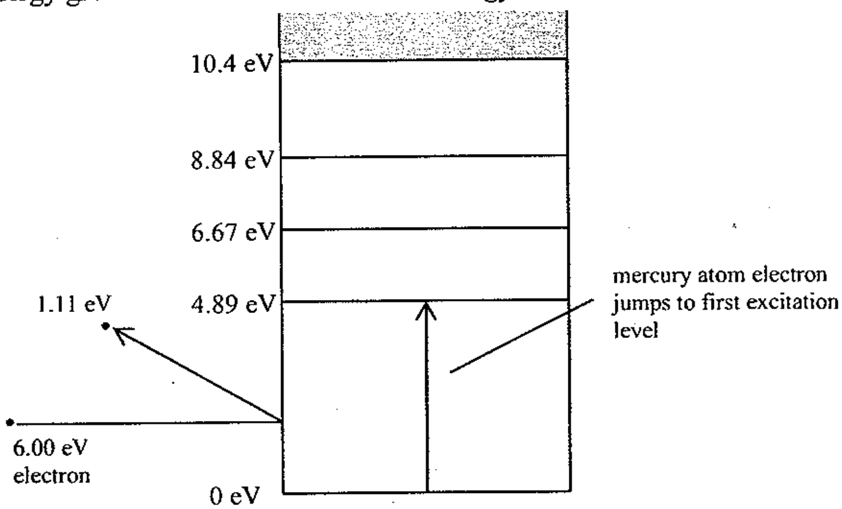
Explanation of emission and absorption spectra

Absorption of energy

Atoms can **absorb energy** in two ways:

1. **Collisions with high energy electrons**. In these collisions the electron in the atom absorbs only the amount of energy corresponding to a jump from the ground state to an excitation state. The incoming electron continues on with the remaining energy. For example, a 6.00 eV incoming electron colliding with a mercury atom, for example, will lose 4.89 eV to the atom and then continue on with an energy of 1.11 eV. Note, for this type of energy absorption, the incoming particle need only have an energy greater than the first excitation energy.

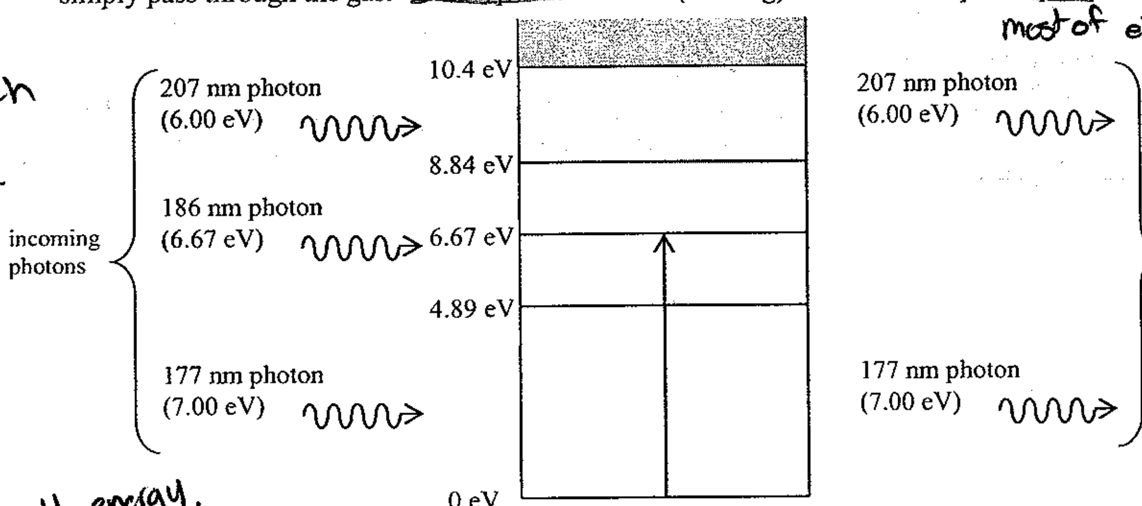
hit with an e⁻ emit's e⁻ with less energy



2. **Absorbing photons.** In this case, the atom will absorb **only** those photons that have energies that **exactly match** the excitation state energies. Since electrons normally reside in the ground state, this means that it will absorb only those photons that match its excitation states from the ground level. Therefore, when full spectrum white light is sent through a gas, only those wavelengths of light that correspond to the excitation states of the gas are absorbed by the gas. The remaining wavelengths simply pass through the gas. This explains the dark (missing) lines for absorption spectra.

hit with light

most of e⁻ are in lowest level light brings e⁻ up levels + only a few photons released.



takes all energy, nothing left over

- all or none effect

- no intermediate effect

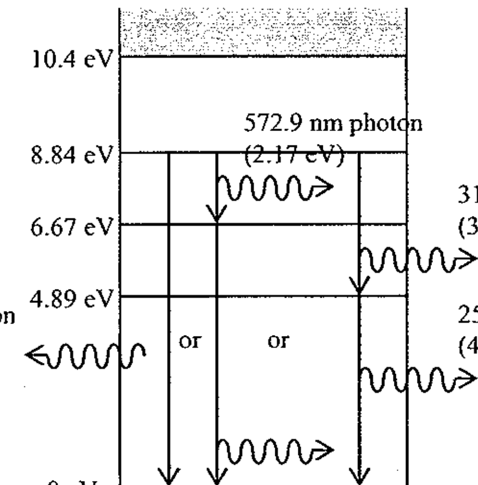
Release of energy

Once atoms have been excited they will eventually fall back to the ground state. Some atoms, like hydrogen, will return to the ground state immediately after being excited. Other atoms, like phosphorous, can stay in an excited state for hours before returning to the ground state.

Atoms can fall back to the ground state in one of two ways:

⇒ The atom can fall **straight** back to the ground state from the excitation state. In this case, one high energy photon is emitted.

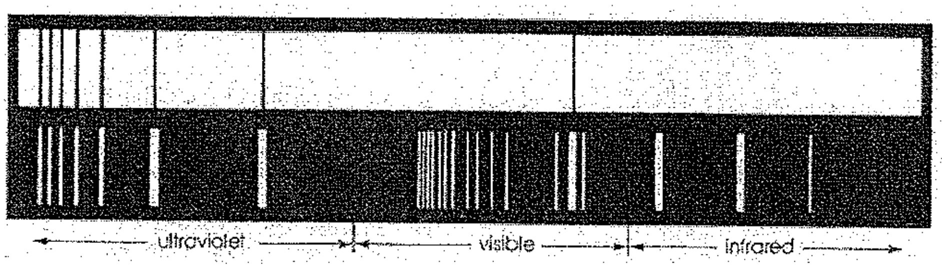
⇒ The atom can fall through a **series of intermediate** excitation states to the ground state. In this case, several lower energy photons will be emitted.



The emission of photons when atoms fall back toward the ground state explains two things about emission spectra:

1. Bright lines of emission spectra correspond with the dark lines of absorption spectra for the same element or molecule.
2. The presence of more lines in emission spectra compared to absorption spectra can be explained by the intermediate jumps that can occur when atoms fall toward their ground state. more lines = more ways to get to ground state.

When emission spectra are compared with the absorption spectra for the same element or molecule, the position of the dark lines in the absorption spectra corresponded exactly with the position of the bright lines in the emission spectra. However, there were always more lines in the emission spectrum than in the absorption spectrum.



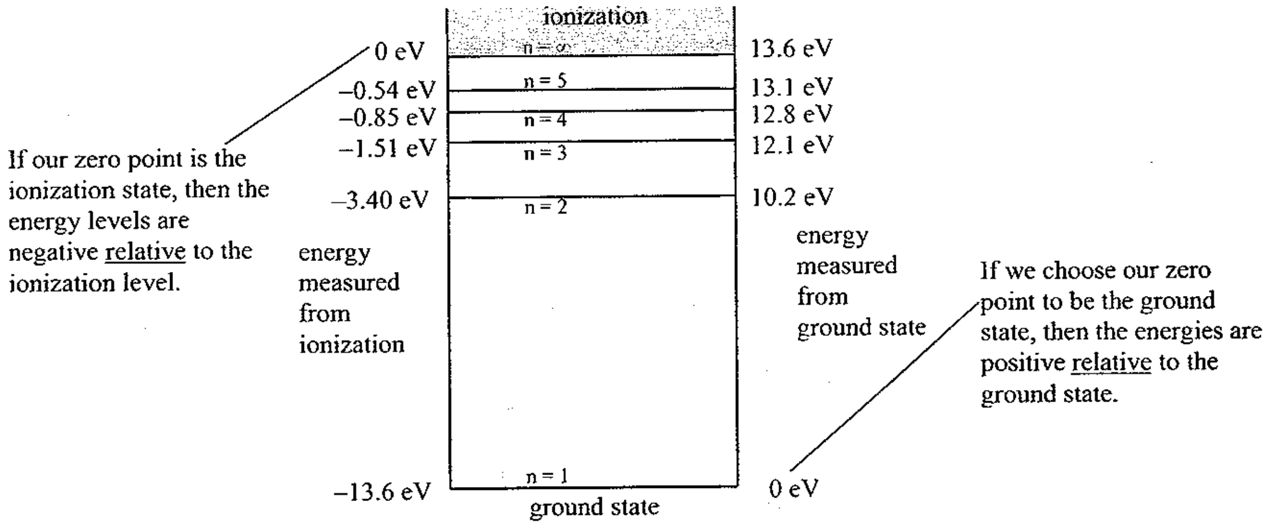
Emission and absorption spectrun for sodium vapour.

emission → falling down e^- levels
absorption → raising e^- levels
} due to all or none.

Bohr Model of the Atom

In 1913 Neils Bohr published a new model for the atom that accounted for emission and absorption spectra, Rutherford's experiment, and the particle nature of light. The model is based on three **postulates.**

1. Atoms may exist in any one of several states that do not involve the emission of or the absorption of EM radiation. These are called **stationary states** in which an atom has different amounts of energy. The Bohr model is often represented as an electron energy level chart. Note that the sign of the energy depends on where we place our zero value.



2. Emission and absorption of EM radiation corresponds to a sudden shift from one stationary state to another.

   E_{photon} ([redacted]) = $\Delta E_{atom} = E_f - E_i$ ([redacted].)

   E_{photon} ([redacted]) = $\Delta E_{atom} = E_i - E_f$ ([redacted]

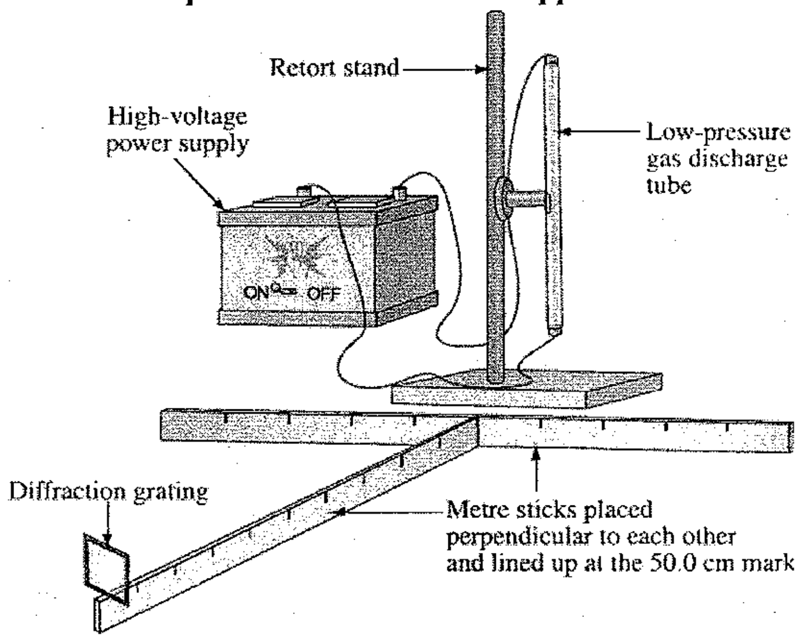
3. The angular momentum of electrons in atoms is **quantized**. In other words, e[redacted]

Use the following information to answer the next three questions.

A group of students is given a low-pressure helium gas-discharge tube, a high-voltage power supply with wire leads, a retort stand with clamps for holding the discharge tube, a diffraction grating, and two metre sticks.

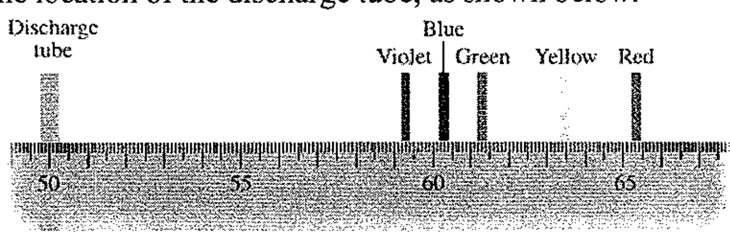
The group clamps the gas-discharge tube into a vertical position and connects it to the power supply. A metre stick is placed horizontally, directly in front of the discharge tube so that the tube is lined up with the 50.0 cm mark. The second metre stick is placed perpendicular to the first metre stick, directly in line with the center of the discharge tube. Finally, a diffraction grating is placed 100 cm from the low-pressure helium gas-discharge tube. The diagram below illustrates the set-up.

Perspective View of Student Apparatus



When the power supply is switched on, an electric current passes through the gas, and the tube emits a pinkish-yellow light.

Using a diffraction grating etched with lines that are spaced 4.35×10^{-6} m apart, the students observe a series of brightly coloured spectral lines to the right of the location of the discharge tube, as shown below.



The yellow spectral line is significantly brighter than the other lines.

73. *If the students replace the diffraction grating with one that has more lines per millimetre etched onto it, then the red spectral line will be observed __ **i** ___ the discharge tube. In order to keep the red spectral line in approximately the same position as in the original observations, the students would have to move the diffraction grating __ **ii** __ the discharge tube.*

The statements above are completed by the information in row

Row	*i*	*ii*
A.	closer to	closer to
B.	closer to	farther from
(C)	farther from	closer to
D.	farther from	farther from

Numerical Response

26. The wavelength of the yellow spectral line for helium, based on the students' observations, expressed in scientific notation, is ***a.bc*** × 10^{-d} m. The values of ***a***, ***b***, ***c***, and ***d*** are _____, _____, _____, and _____.

(Record the **four digits** of your answer in the numerical-response section on the answer sheet.)

$\lambda = \frac{(4.35 \times 10^{-6})(.135)}{1.1 m}$

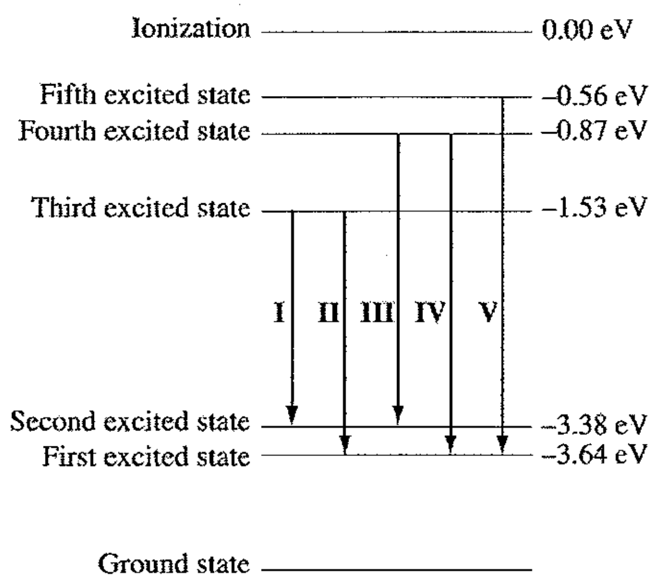
$= 5.87 \times 10^{-7} m$

Continuous	absorption spectrum	Emission
Heated Solid	Cool - low pressure gas	heated low pressure gas.

$x = 63.5 - 50 = 13.5$

Use the following additional information to answer the next question.

The students are also given the following reference energy level diagram for helium. Transitions I, II, III, IV, and V correspond to the spectral lines that were observed by the students.



74. Which of the following rows matches the transition corresponding to the violet spectral line, and the frequency of a photon corresponding to the violet spectral line?

V highest f (E)

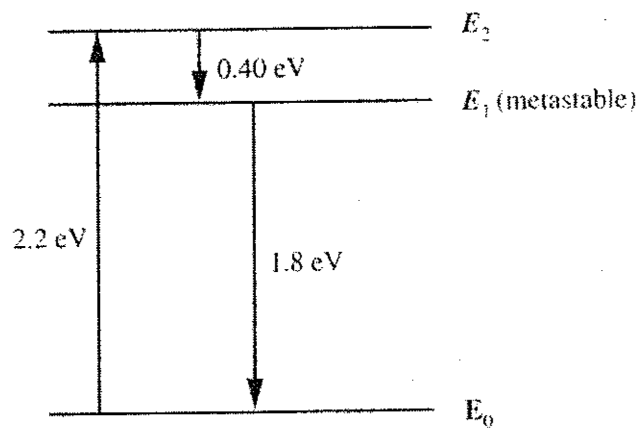
Row	**Transition corresponding to the violet spectral line**	**Frequency of a photon corresponding to the violet spectral line**
A.	I	7.44×10^{14} Hz
B.	I	4.47×10^{14} Hz
C.	V	7.44×10^{14} Hz
D.	V	4.47×10^{14} Hz

$\Delta E = E_f - E_i$
$= -3.64 - (-.56)$
$= -3.08$ eV

$E = hf$
$3.08 = hf$
7.44×10^{14} Hz $= f$

Use the following information to answer the next question.

Energy States of Chromium in a Ruby Crystal Laser



75. What is the frequency of light emitted from the laser when the electron in the chromium atom goes from state E_1 to state E_o?

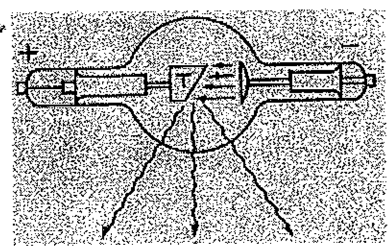
$E = hf$

$\frac{1.8}{4.14\times10^{-15}} = f$

A. 9.7×10^{13} Hz
(B) 4.3×10^{14} Hz
C. 5.3×10^{14} Hz
D. 1.1×10^{15} Hz

X-rays

~~X-rays are produced by the rapid deceleration of electrons as they strike the anode in a cathode ray~~ tube. In the diagram to the right, electrons are accelerated toward a tungsten target. When they strike the target, the kinetic energy of the electrons is converted into X-ray radiation.



electric potential energy → ~~kinetic energy of electron~~ → photon energy

∴ electric potential energy = photon energy

$$\Delta E_{electric} = E_{photon} \qquad \Delta E_{electric} = E_{photon}$$

$$q\Delta V = hf \qquad \text{or} \qquad q\Delta V = \frac{hc}{\lambda}$$

$$f = \frac{q\Delta V}{h} \qquad \lambda = \frac{hc}{q\Delta V}$$

Use the following information to answer the next three questions.

> X-rays were discovered in 1895 by Roentgen. In the cathode ray tube that he used, a high electrical potential difference between the anode and the cathode accelerated the electrons. The electrons then collided with a copper target.
>
> Three Types of Energy
>
> **1** electrical potential energy
> **2** electromagnetic energy
> **3** kinetic energy

Numerical Response

27. In the production of X-rays, the three types of energy listed above occur in order from _1_ to _3_ to _2_.

(Record your **three digit** answer in the numerical-response section on the answer sheet.)

Numerical Response

28. The minimum accelerating voltage necessary to produce an X-ray with a wavelength of 6.25×10^{-11} m, expressed in scientific notation, is $\mathbf{a.bc} \times 10^{\mathbf{d}}$ V. The values of **a**, **b**, **c**, and **d** are _1_, _9_, _9_ and _4_.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

$E_{electron} = E_{photon}$

$qV = \frac{hc}{\lambda}$

$1.6e^{-19} \cdot V = \frac{h \cdot c}{6.25 \times 10^{-11}}$

$= 1.99 \times 10^{4}$

76. The damage to biological organisms that X-rays can cause is a result of their

A. high speed
B. small mass
(C) short wavelength
~~D. high radioactivity~~

high energy → short wavelength (ionizing radiation)

The Compton effect

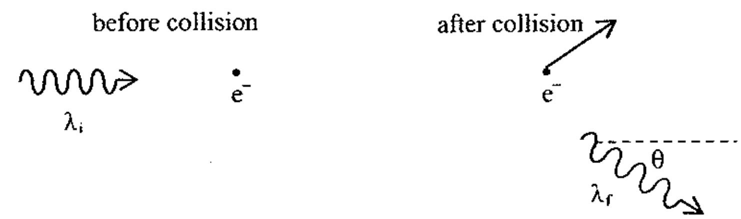
→ particle Compton = momentum

Compton derived the equation(s) that described the momentum of a photon

$$p = \frac{h}{\lambda} \quad \text{and} \quad E = pc$$

→ photon

Compton bombarded **electrons** with x-ray photons. He measured the wavelength of the incoming x-ray (λ_i) and the wavelength of the scattered x-ray (λ_f) that scattered through an angle θ.



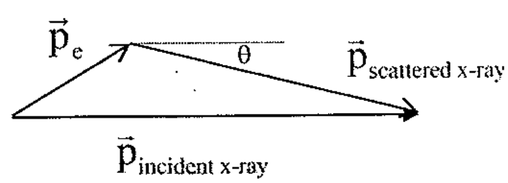
The collision between the x-ray photon and the electron is a purely elastic collision. Therefore, in terms of the **conservation of energy** we have

$$E_{\text{incoming x-rays}} = E_{\text{K electron}} + E_{\text{scattered x-rays}}$$

$$\frac{hc}{\lambda} = \tfrac{1}{2}mv^2 + \frac{hc}{\lambda'}$$

And in terms of the **conservation of momentum**, the collision between the incoming x-ray and the electron yields

$$\vec{p}_{\text{incident x-ray}} = \vec{p}_e + \vec{p}_{\text{scattered x-ray}}$$



Utilising both the conservation of energy and the conservation of momentum, along with an application of Einstein's special theory of relativity, Compton derived the following relationship for the change in wavelength of the x-ray photon.

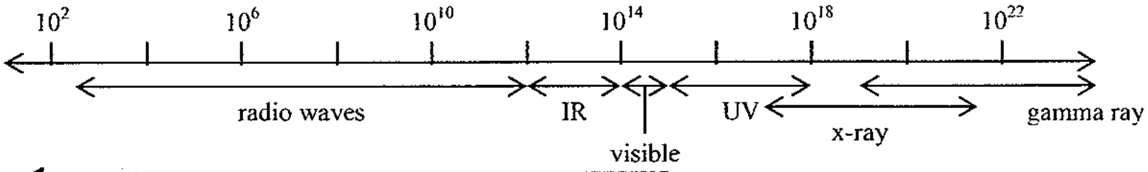
$$\Delta\lambda = \lambda_f - \lambda_i = \frac{h}{mc}(1 - \cos\theta)$$

→ x-ray scattered angle

where m is the mass of the electron and θ is the angle through which the x-ray scatters.

Wave-particle duality

It seems that light can be thought of as a particle <u>and</u> as a wave, but which is correct? The answer is, both are correct. [redacted]e and the properties that we observe depend (a) on the energy ($E = hf$) of the light and (b) on the kind of experiment we decide to conduct. Generally speaking, th[redacted]e. Consider the electromagnetic (light) spectrum:



For low frequency, [redacted]ergy light the [redacted]nature of light dominates.

For high frequency, h[redacted]gy light the [redacted] nature of light dominates.

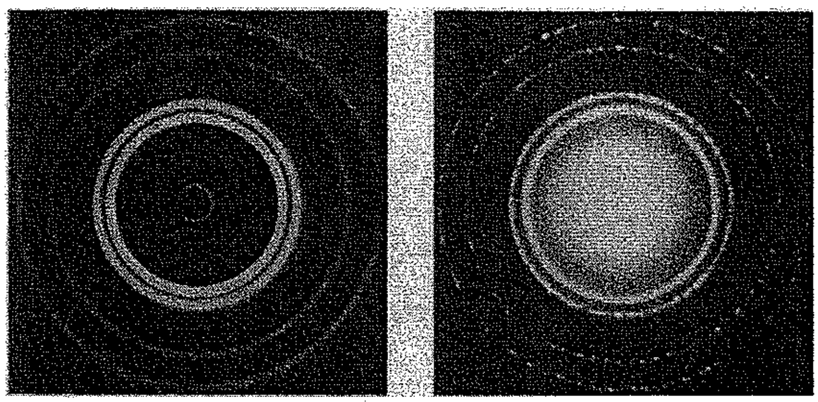
Wavelengths of matter

When Compton had suggested through his x-ray scattering experiments that light photons had particle-like characteristics, Louis de Broglie wondered if the **converse** was true – could subatomic particles like the electron behave like a wave? The **wavelength of a particle** is given by

particle $$\lambda = \frac{h}{p} = \frac{h}{mv}$$

As the speed of the particle become larger, its wavelength is shorter.

Since diffraction was the easiest phenomena to demonstrate the wavelike nature of something, Young had done so for light in 1804, de Broglie and his associates began to find some way to demonstrate the diffraction of electrons. The pictures to the right indicate the results of x-ray and electron diffraction in aluminum.



x-ray diffraction pattern from aluminum foil

electron diffraction pattern from aluminum foil

So why don't moving objects in our everyday experience demonstrate wavelike behaviour? If we use a 1.00 kg mass traveling at 10.0 m/s, de Broglie's equation gives us a wavelength of

$$\lambda = \frac{h}{mv} = \frac{6.63\times10^{-34}\ \text{J}\cdot\text{s}}{1.0\text{kg}(10.0\,\text{m/s})} = \mathbf{6.63 \times 10^{-33}\ m}$$

This wavelength is far too small to be seen in the everyday world of objects. Therefore, we are not aware of the wave nature of everyday material objects.

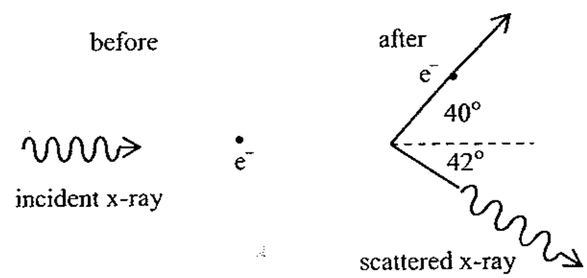
For the diploma exam:

- ⇒ The de Broglie equation is not on the formula sheet, but it is often given as part of a question (see below).
- ⇒ Phenomena like Planck's equation, the photoelectric effect, the Compton effect, and de Broglie's ideas are all expressions of wave-particle duality.

photon has no mass

Use the following information to answer the next question.

Consider the following collision of an incident x-ray on a stationary electron.



The diagram is not drawn to scale.

Numerical Response

29. The change in wavelength of the x-ray, expressed in scientific notation, is $\boldsymbol{a.b} \times 10^{-cd}$ m. The values of a, b, c, and d are ____ , ____ , ____ , and ____.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

$$\Delta\lambda = \frac{h}{m \cdot c}(1-\cos\theta)$$

$$= \frac{6.63\times10^{-34}}{9.11\times10^{-31}\cdot 3e^{8}}(1-\cos(42))$$

$$= 6.2\times10^{-13}\text{ m}$$

Numerical Response

30. A photon has a momentum of 4.0×10^{-23} N·s. The frequency of the photon, expressed in scientific notation, is **a.b** $\times 10^{cd}$ Hz. The values of **a**, **b**, **c**, and **d** are ____, ____, ____ and ____.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

* $E = pc$

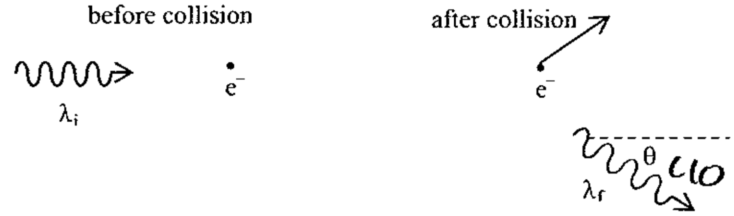
$hf = pc$

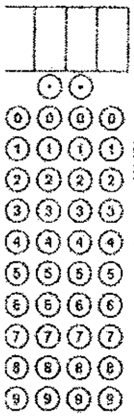
$$= \frac{4.0\times10^{-23}\cdot 3e^{8}}{6.63\times10^{-34}}$$

$$= 1.8\times10^{19}$$

Use the following information to answer the next question.

Consider the following collision of an incident x-ray on a stationary electron.





Numerical Response

31. If the incident x-ray has a wavelength of 1.658×10^{-11} m and the scattered x-ray scatters at an angle of 40.00°, the wavelength of the scattered x-ray photon, expressed in scientific notation, is ***a.bcd*** $\times 10^{-11}$ m. The values of ***a***, ***b***, ***c***, and ***d*** are ____, ____, ____, and ____.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

$$\Delta\lambda = \frac{h}{m \cdot c}(1 - \cos\theta)$$

$$= \frac{6.63\times10^{-34}}{9.11\times10^{-31} \cdot 3e8}(1-\cos(40))$$

$$= 5.675\times10^{-13} + 1.658\times10^{-11}$$

$$= 1.715\times10^{-11}\ m$$

$$\left(\begin{aligned}\Delta\lambda &= \lambda_f - \lambda_i \\ \lambda_f &= \Delta\lambda + \lambda_i\end{aligned}\right)$$

77. The explanation of the Compton effect requires the

A. wave nature of light - double slit, interference

(B) particle nature of light

C. probabilistic nature of quantum physics

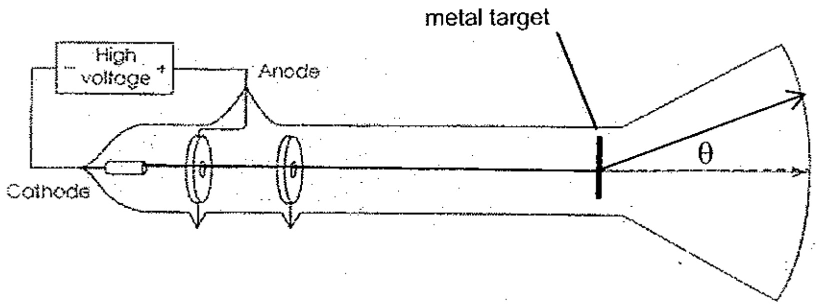
D. ejection of electrons from a metal surface

Compon effect is dealing with momentum

momentum is a particle property.

Use the following information to answer the next two questions.

In a glass vacuum tube, electrons are accelerated through a potential difference toward a metal target.



(The diagram is not drawn to scale.)

According to de Broglie, the wave nature of the electrons results in their diffraction through an angle θ. The wavelength of the electrons may be calculated using

$$\lambda = \frac{h}{p}$$

The electrons are accelerated through a potential difference of 615 V and the spacing between the atoms in the metal target is 0.234 nm.

Numerical Response

32. The angle for the first order maximum is ***ab.c*** degrees. The values of ***a***, ***b***, and ***c*** are ____, ____, and ____.

(Record all **three digits** of your answer in the numerical-response section on the answer sheet.)

(1) $qV = \frac{1}{2}mv^2$

$1.6e^{-19} \cdot 615 = .5)(9.11\times10^{-31})(v)^2$

$1.47\times10^{8} = v$

(2) $\lambda = \frac{h}{m \cdot v}$

$= \frac{6.63\times10^{-34}}{9.11\times10^{-31} \cdot 1.47\times10^{8}}$

$= 4.95\times10^{-11}$ m

(3) $\lambda = \frac{d\sin\theta}{n}$

$4.45\times10^{-11} = \frac{.234\times10^{-9} \cdot \sin\theta}{1}$

$12.2 = \sin\theta$

Use the following additional information to answer the next question.

Two of the following physics principles were used in the calculation of the angle.

1. uniform motion (balanced forces)
2. uniformly accelerated motion (unbalanced forces)
3. circular motion (unbalanced forces)
4. conservation of momentum
5. conservation of energy — Electron potential → E_K
6. conservation of mass-energy
7. conservation of charge
8. conservation of nucleons
9. wave-particle duality — Electron diffracts like a wave.

Numerical Response

33. In the **correct order**, the principles that were applied in the angle calculation from Numerical Response 32 were 5 and 9.

(Record your **two digit** answer in the numerical-response section on the answer sheet.)

78. For which of the following explanations did the diffraction of high-speed electrons provide experimental support?

A. Bohr's explanation of line spectra
B. Compton's explanation of the Compton effect → particle
C. Einstein's explanation of the photoelectric effect → particle.
(D.) De Broglie's explanation of wave nature of matter

UNIT V – NUCLEAR PHYSICS (~10%)

Up to this point in our discussion of the nature of the atom we have been studying how the electrons behave around the nucleus. The study of the electrons around the nucleus is referred to as **atomic physics**. Now we turn our attention to the nucleus (**nuclear physics**) and the fundamental particles that atoms are composed of (**particle physics**).

Symbols for atoms and particles may be written as

[redacted]
(# of protons + # of neutrons = # of nucleons)

A [redacted] X — **X** is the atom's or particle's symbol

[redacted] (# of protons)
or, more generally, its charge

For example, the element tungsten-186 is written as $^{186}_{74}W$ which means that it has 74 protons and (186 – 74 =) 112 neutrons.

Isotopes of an element have the same atomic number but a different atomic mass. For example, three isotopes of carbon are

carbon-12	carbon-13	carbon-14
$^{12}_{6}C$	$^{13}_{6}C$	$^{14}_{6}C$

We calculate the **theoretical mass** for a particular isotope by adding together the masses of protons and neutrons

$$m_{theoretical} = m_{protons} + m_{neutrons}$$

Using a mass spectrometer, we are able to find the **measured** mass. Except for hydrogen, the **measured value is always less than the theoretical value**. The difference is called the **mass defect** (Δm). In general

$$\Delta m = m_{measured} - m_{theoretical}$$

Based on the idea of **mass-energy equivalence**

$$\Delta E = \Delta m c^2$$

→ mass converted to energy

physicists interpreted the mass defect as the **binding energy** that holds the protons and neutrons together in the nucleus. Due to the large repulsive electrostatic forces between protons, a large amount of energy and large forces are required to hold the nucleus together. The binding energy, resulting from what was later called the **strong nuclear force**, is equivalent to the mass defect using Einstein's equation.

Use the following information to answer the next two questions.

The measurements given below indicate that the uranium-235 nucleus has a smaller mass than the mass of a corresponding number of free protons and neutrons. This difference in mass is called the mass defect.

Einstein's concept of mass-energy equivalence, $E = m c^2$, can be used to predict the energy that binds a nucleus together by using the mass defect.

mass of uranium-235 nucleus = 3.9021×10^{-25} kg
mass of proton = 1.6726×10^{-27} kg
mass of neutron = 1.6749×10^{-27} kg

$235 - 92 = 143$ → neutron)
↓ protons

Numerical Response

34. The mass defect of uranium-235, expressed in scientific notation, is **a.bc** $\times 10^{-w}$ kg. The values of **a**, **b** and **c** are ____, ____, ____ and ____.

(Record your **three-digit** answer in the numerical-response section on the answer sheet.)

Δm = separated nucleons − mass nucleus
$\Delta m = (92 \times 1.6726 \times 10^{-27} + 143 \times 1.6749 \times 10^{-27}) - 3.9021 \times 10^{-25}$
$\Delta m = 3.933899 \times 10^{-25} - 3.9021 \times 10^{-25}$
$\Delta m = 3.18 \times 10^{-27}$ kg

Numerical Response

35. The nuclear binding energy of uranium-235, expressed in scientific notation, is **a.bc** $\times 10^{w}$ eV. The values of **a**, **b**, and **c** are ____, ____, ____ and ____.

(Record your **three-digit** answer in the numerical-response section on the answer sheet.)
*You can receive marks for this question even if the previous question was answered incorrectly.

$E = mc^2$
$= 3.1799 \times 10^{-27} \cdot (3e^8)^2$
$= \dfrac{2.86 \times 10^{-10}\ J}{1.60 \times 10^{-19}\ J/eV}$
$= 1.79 \times 10^{9}$ eV

Nuclear equations – conservation of charge & nucleons

Nuclear interactions are represented by **nuclear equations**. Nuclear interactions can involve the disintegration of a nucleus, the transmutation of a nucleus and a host of other interactions. In nuclear equations, the original isotope(s) is/are often referred to as the **parent** isotope(s), while the final isotope(s) is/are called the **daughter** isotope(s). When writing nuclear equations it is important to **conserve electric charge** and to **conserve the number of nucleons**. In other words:

⇒ The sum of the **atomic numbers** on the parent side equals the sum of the atomic numbers on the daughter side.

⇒ The sum of the **atomic masses** on the parent side equals the sum of the atomic masses on the daughter side.

Nuclear reactions

The presence of such huge quantities of energy within nuclei explains why nuclear reactions are so energetic. While the electron of a hydrogen atom can be ionized with a mere 13.6 eV, it takes about 8 MeV or 8 000 000 eV of energy to remove a nucleon from a nucleus. For this reason, gram for gram, a nuclear reaction can liberate millions of times more energy than a chemical reaction. There are four basic types of nuclear reactions: induced nuclear transmutations, fission, fusion, and radioactivity.

Induced nuclear transmutations

It is possible to bring about or "induce" the disintegration of a stable nucleus by striking it with another nucleus, an atomic or subatomic particle, or a γ-ray photon. In 1919, for example, Ernest Rutherford observed that when an α particle ($^{4}_{2}He$) strikes a nitrogen nucleus ($^{14}_{7}N$), an oxygen nucleus ($^{17}_{8}O$) and a proton ($^{1}_{1}H$) are produced. This nuclear reaction is written as

$$^{4}_{2}He + ^{14}_{7}N \longrightarrow ^{17}_{8}O + ^{1}_{1}H$$

Since the incident α particle induces the transmutation of nitrogen into oxygen, this reaction is an example of an induced nuclear transmutation.

Fission reactions

Break apart.

In nuclear fission we take heavy elements and break them apart to produce smaller nuclei. The process involves bombarding particular nuclei with neutrons. A neutron captured by a fissionable nucleus results in an unstable nucleus which splits. In the process some of the binding energy of the heavy element is converted into radiant energy.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + \text{energy}$$

Fusion reactions

bind together

In nuclear fusion we take light elements and force them together to form larger sized atoms. Examples are the fusion of two deuterium ($^{2}_{1}H$) nuclei to form a helium-3 nucleus.

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + ^{1}_{0}n + \text{heat}$$

or the fusion of tritium ($^{3}_{1}H$) and deuterium ($^{2}_{1}H$) to form a helium-4 nucleus

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

The problem to overcome in fusion reactions is to bring the parent nuclei together so that the electrostatic repulsion is overcome and the strong nuclear force can take over. Nuclear fusion reactions require extremely high pressures and temperatures to get them started. Such pressures and temperatures are found within the core of a star like our Sun. In a star the nuclei are forced together due to the enormous gravitational forces involved. In turn, the forces created by the fusion reactions try to explode the star. Thus there is a balance between the forces of gravity and the forces produced by the fusion reactions.

Radioactivity

In 1896 Henri Becquerel discovered three new rays being emitted by a sample of uranium ore. These rays were quickly named **alpha rays**, **beta rays** and **gamma rays**. The emission of these rays is now referred to as **radioactive decay** and the rate of release of these rays is called the **decay rate** or **radioactivity** (or simply **activity**). These rays have the following properties:

α rays

- are helium nuclei with a charge of +2e
- are emitted for the nucleus at high speed but are stopped by a few centimeters of air, a few sheets of paper or your skin
- emission of particles results in [redacted]e emitting element changes to a new element)

An example of α decay is the transmutation of uranium 238 to thorium 234.

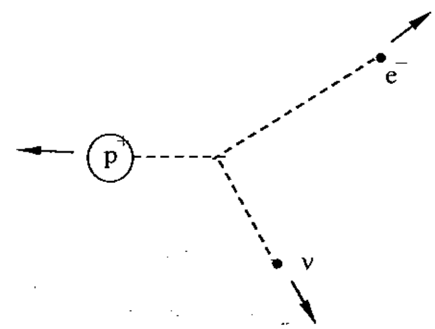
$$^{238}_{92}U \rightarrow {}^{4}_{2}He + {}^{234}_{90}Th$$

parent nucleus | α particle (helium nucleus) | daughter nucleus

β rays

- are electrons (charge = −1) or positrons (charge = +1)
- are emitted with a variety of speeds, some approaching the speed of light, have greater ranges than α particles, and are able to penetrate several millimeters of aluminum
- emission of β particles results in [redacted]

When the conservation laws of charge, energy, momentum and angular momentum were applied to alpha decay there were no problems. However, beta decay did not work out so easily. Eventually a new particle, the neutrino, was predicted in order for the conservation laws to hold. In addition, years later another type of **beta positive** decay was discovered in addition to beta negative. Thus



β^- **decay** involves the transformation of a **neutron into a proton and an electron which also produces an antineutrino**

$$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + \bar{\nu}$$

β^- decays involving the nucleus of an atom have the general form

$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta + \bar{\nu}$$

β^+ **decay** involves the transformation of a **proton into a neutron and a positron which also produces a neutrino**

$$^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}e + \nu$$

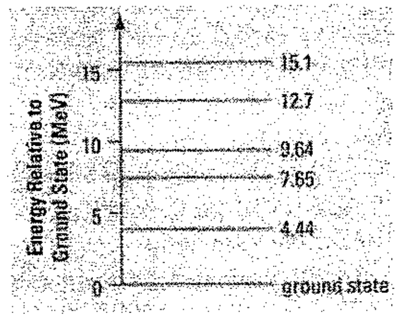
β^+ decays involving the nucleus of an atom have the general form

$$^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{1}\beta + \nu$$

γ rays

- are photons (or EM waves) of frequencies higher than X-rays
- are neutral in charge
- are able to penetrate 30 cm or more of lead and kilometers of air
- emission of γ photons **does not cause transmutation**

Like the excitation of atoms nuclei also have a series of excitation energy levels. When making a transition to a lower-energy state, a nucleus emits a gamma-ray photon, similar to the photon emitted when an electron in an atom moves to a lower energy level. However, the difference in energy is much greater for a nucleus – note that the energy scale is in MeV. Gamma decay does not change either the atomic number or the atomic mass.



All three of alpha, beta and gamma rays can be absorbed by matter and all three are also **ionizing radiation** meaning they can cause atoms in the absorbing matter to lose or gain electrons. In living organisms this can be a seriously damaging process leading to the development of serious medical problems such as cancers.

Example

Write complete nuclear equations for the following:

A. The β^- decay of actinium-230.

$${}^{230}_{89}\text{Ac} \rightarrow {}^{0}_{-1}\text{e} + {}^{?}_{?}? + \bar{\nu}$$

Atomic mass: 230 = 0 + A
A = 230

Atomic number: 89 = (-1) + Z
Z = 90
(element 90 is Th - thorium)

solution

$${}^{230}_{89}\text{Ac} \rightarrow {}^{0}_{-1}\text{e} + {}^{230}_{90}\text{Th} + \bar{\nu}$$

B. The β^+ decay of neptunium-234.

$${}^{234}_{93}\text{Np} \rightarrow {}^{0}_{+1}\text{e} + {}^{?}_{?}? + \nu$$

Atomic mass: 234 = 0 + A
A = 234

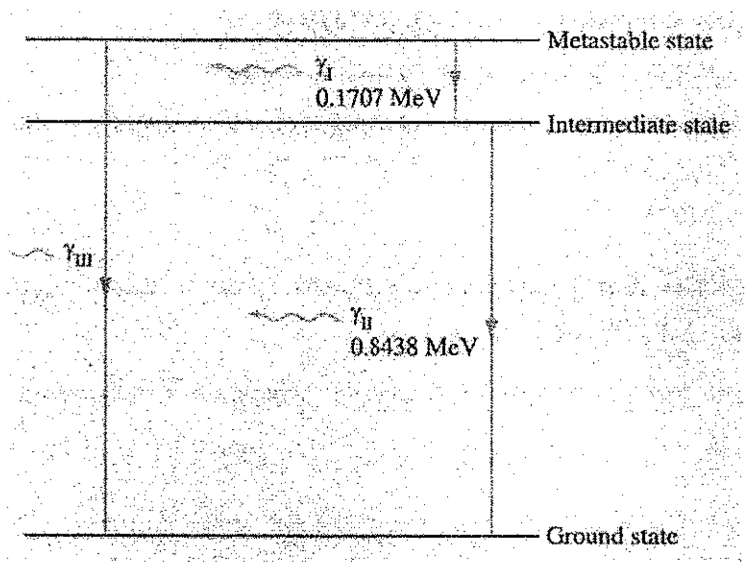
Atomic number: 93 = (+1) + Z
Z = 92
(element 92 is U - uranium)

solution

$${}^{234}_{93}\text{Np} \rightarrow {}^{0}_{+1}\text{e} + {}^{234}_{92}\text{U} + \nu$$

Use the following information to answer the next two questions.

Magnesium-27 is an isotope of magnesium that undergoes beta negative decay. The daughter nucleus of this decay is initially produced in a metastable, excited state. Three gamma photons may be emitted as the nucleus makes transitions from this excited state to the ground state. These transitions are shown in the diagram below.



79. The daughter nucleus produced by the beta negative decay of magnesium-27 is

A. $^{23}_{10}Ne$

B. $^{27}_{11}Na$

C. $^{27}_{13}Al$

D. $^{31}_{14}Ne$

$^{27}_{12}Mg \rightarrow ^{0}_{-1}\beta + ^{27}_{13}Al + ^{0}_{0}\bar{\nu}$

80. The longest wavelength of gamma radiation that can be emitted by the excited daughter nucleus is → lowest energy!

A. 1.22×10^{-12} m

B. 1.47×10^{-12} m

C. 1.85×10^{-12} m

D. 7.28×10^{-12} m

$E = \frac{h \cdot c}{\lambda}$

$.1707 \times 10^{6} = \frac{h \cdot c}{\lambda}$

Use the following information to answer the next question.

Each of the following statements gives a characteristic of either a fusion reaction or a fission reaction.

1	A heavy nucleus is split into two or more lighter nuclei.
2	Two nuclei are combined into one.
3	It is the dominant nuclear reaction in the sun.
4	The products of the reaction are harmless.
5	The reaction produces radioactive isotopes.
6	Extremely high temperatures are needed to start the reaction.

Numerical Response

36. The statements above that describe nuclear **fusion**, listed in ascending order, are 2, 3, 4, and 6.

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)

Half – life

Radioactive elements do not decay all at once. Their decay rate is governed by a logarithmic or exponential equation:

$$N = N_o \left(\frac{1}{2}\right)^n$$

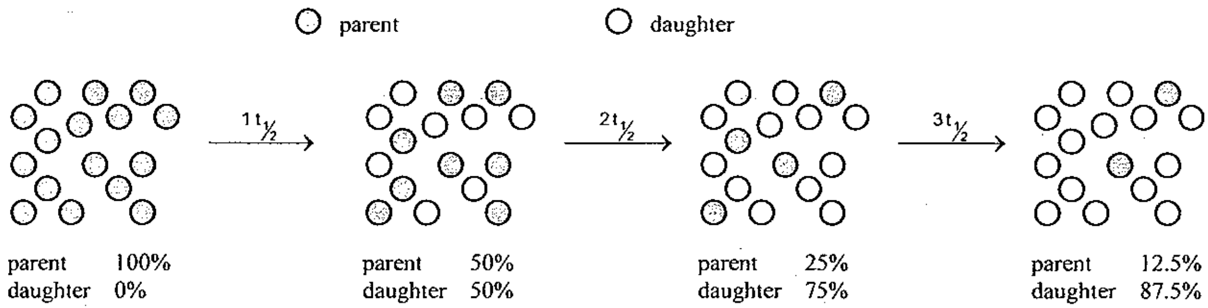
Where N — number of radioactive nuclei remaining or mass remaining or activity of the material

N_o — original number of radioactive nuclei or original mass or original activity of the material

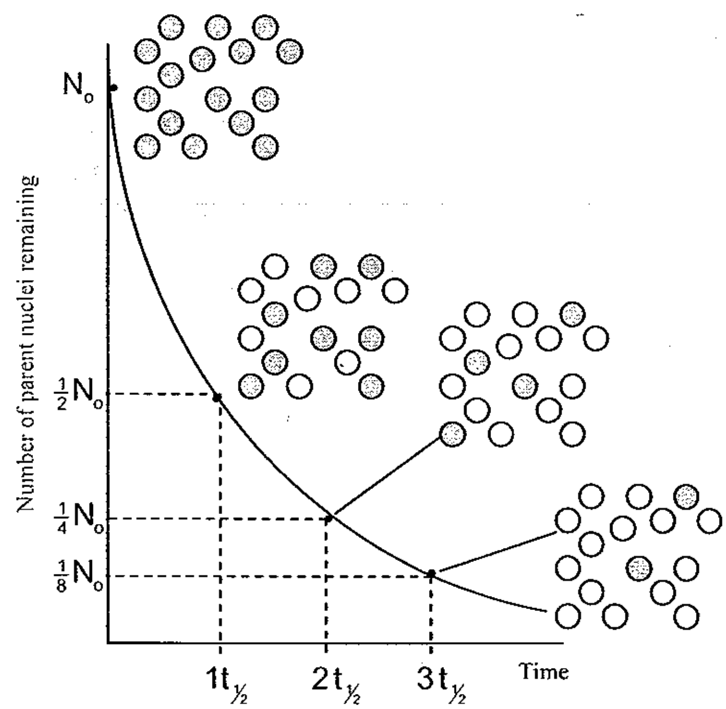
n — number of half lives*

$$n = \frac{t}{t_{1/2}}$$

*A half-life ($t_{1/2}$) is the time it takes for ½ of the parent isotope to decay into the daughter isotope or the time it takes for the radioactivity level to decrease by ½. Half-lives can range from a few trillionths of a second to trillions of years depending on the stability of the isotope.



When a set of data is given, one can graph the results and then determine the half-life. To determine the half-life off a decay curve, find an interval on the vertical axis where the mass or decay rate is decreased by ½. The half-life is the **time** (horizontal axis) for that interval.



Use the following information to answer the next three questions.

> In a number of nuclear power stations, the reaction material is uranium-235. The uranium-235 will spontaneously decay to produce thorium-231 plus at least one other particle. The half-life of uranium-235 is 7.0×10^8 years.

81. One of the other particles that is produced during the decay process must be

(A.) an alpha particle
B. an electron
C. a neutron
D. a proton

$^{235}_{92}U \rightarrow ^{231}_{90}Th + ^{4}_{2}\alpha$

82. How long would it take 10.0 g of uranium-235 to decay to 1.25 g?

A. 9.9×10^{-2} y
B. 1.8×10^{8} y
C. 1.4×10^{9} y
(D.) 2.1×10^{9} y

① $N = N_0 \cdot .5^n$
$1.25 = 10 \cdot 1/2^n$
$.125 = .5^n$
$\log .125 = \log .5\, n$
$3 = n$

② $n = \frac{time}{t_{1/2}}$
$3 = \frac{time}{7.0 \times 10^8}$
$time = 2.1 \times 10^9 a$

83. The fission of uranium-235 will release 200 MeV of energy per atom. This energy is related to the

A. initial kinetic energy of the initiating neutron
B. conversion of a nucleon to energy
C. formation of beta radiation
(D) mass defect of the nucleus

$E = mc^2$
↖ mass defect is the amount of mass converted into Energy.

Use the following information to answer the next two questions.

> Cobalt-60 is a common radiation source used in cancer treatment. The half-life of cobalt-60 is 5.2 years. A cobalt-60 nucleus decays by emitting a beta negative particle and a gamma photon.

84. Which of the following equations describes the decay of cobalt-60?

A. $^{60}_{27}Co \rightarrow ^{60}_{28}Ni + ^{0}_{-1}\beta + \gamma + \nu$
(B.) $^{60}_{27}Co \rightarrow ^{60}_{28}Ni + ^{0}_{-1}\beta + \gamma + \bar{\nu}$
C. $^{60}_{27}Co \rightarrow ^{60}_{26}Fe + ^{0}_{-1}\beta + \gamma + \nu$
D. $^{60}_{27}Co \rightarrow ^{60}_{26}Fe + ^{0}_{-1}\beta + \gamma + \bar{\nu}$

assume $N = 100$

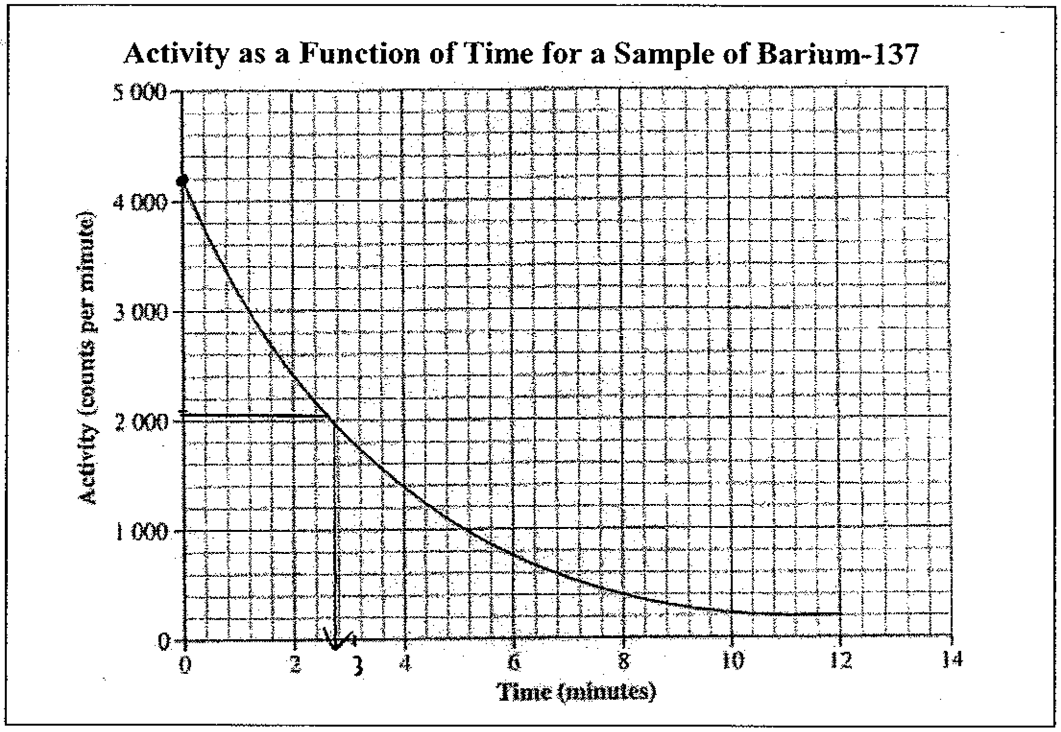
$N_0 = 100 \cdot 1/2^{\frac{15.6}{5.2}}$

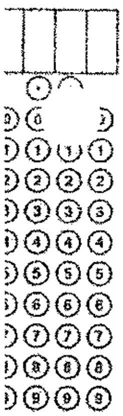
$N = 12.5$

Numerical Response

37. The percentage of cobalt-60 remaining after 15.6 years is 12.5 %.

Use the following information to answer the next two questions.





Numerical Response

38. The half-life of barium-137 is 2.5 minutes.

(Record your **two digit** answer in the numerical-response section on the answer sheet.)

85. The activity of this sample after 3 half-lives have elapsed is approximately

A. 260 counts/min

(B.) 520 counts/min

C. 1 900 counts/min

D. 2 080 counts/min

$N_0 = N \cdot .5^n$

$= 4100 \cdot \frac{1}{2}^3$

$= 513\ Bq$

Use the following information to answer the next two questions.

In certain parts of Canada the presence of radioactive radon gas within the basements of homes poses a serious health risk. Radon-222 has a half-life of 3.84 days and it decays through alpha emission.

Numerical Response

39. An 8.82 μg sample of radon-222 decays for 24 hours. The remaining amount of radon-222 in the sample is **a.bc** μg. The values of **a**, **b**, and **c** are ____, ____ and ____.

(Record your **three digit** answer in the numerical-response section on the answer sheet.)

$8.82 \cdot \frac{1}{2}^{\frac{24}{92.16}}$

7.36

86. The product of the alpha decay of radon-222 is

(A.) $^{218}_{84}Po$

B. $^{222}_{86}Po$

C. $^{218}_{84}Rn$

D. $^{218}_{86}Rn$

$^{222}_{86}Rn \Rightarrow {}^{4}_{2}\alpha + {}_{84}$

After Einstein demonstrated that energy and mass are inter-convertible it became apparent that the laws of conservation of mass and conservation of energy were actually aspects of one law – the **conservation of mass-energy**. **This idea allows us to imagine the creation of particles** from kinetic or radiant energy and to imagine the **annihilation of particles** into radiant energy. In this conception we can think of an electron, for example, as having a mass of 9.109 383 x 10^{-31} kg or as an equivalent energy of 0.510999 MeV. Notice that on your Physics Data Sheet, the masses for some first generation fermions are given as energy in eV or MeV over c^2.

$$E_{e^-} = m_{e^-}c^2$$

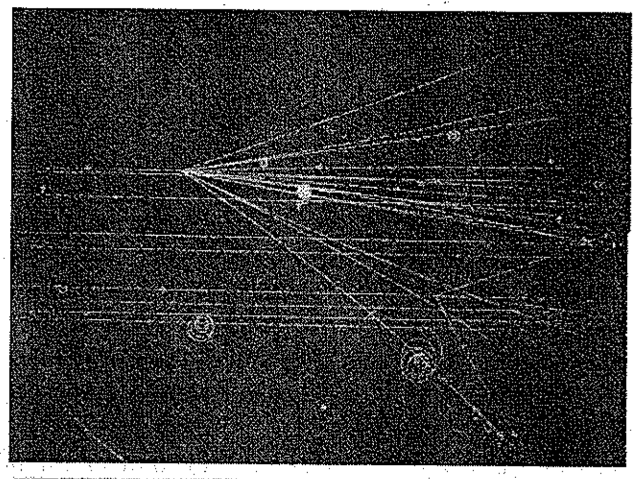
$$E_{e^-} = 9.109383 \times 10^{-31}\text{kg}(2.997925 \times 10^{8}\ \text{m/s})^2$$

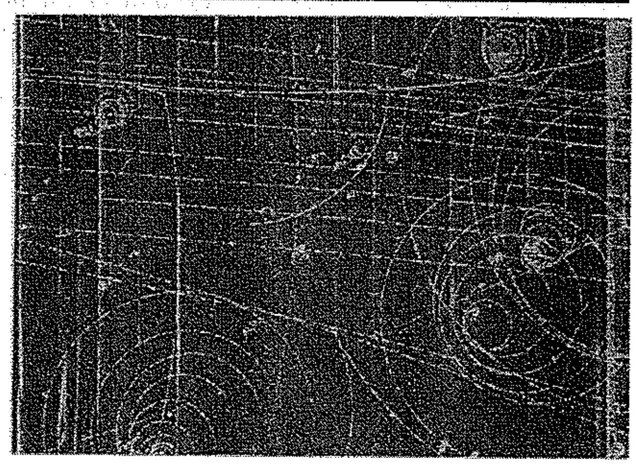
$$E_{e^-} = 8.187107 \times 10^{-14}\text{J} \times \frac{1\text{eV}}{1.602177 \times 10^{-19}\text{J}}$$

$$E_{e^-} = 0.510999\text{MeV}$$

Particle detectors

Subatomic particles are far too small and move too fast to be observed and measured directly. Also, most elementary particles decay into smaller particles very quickly – i.e. 10^{-24} to 10^{-9} s. In order for a detector to sense a particle, there must be an interaction between the particle and the material of which the detector is made. For a **cloud chamber** when a gas is supersaturated with a vapour, the vapour will condense into droplets around the trajectories of charged ions as they pass through the gas. The ions leave behind trails of droplets which can be photographed. This is the same principal that produces vapour trails for airplanes.





In the **bubble chamber**, liquid propane, hydrogen, helium, and xenon are all used. However, liquid hydrogen is used most commonly since the hydrogen nuclei provide target protons for collisions. If a high-speed charged particle passes through the hydrogen, hydrogen ions are formed, and the hydrogen boils a few thousandths of a second sooner around these ions than in the rest of the container.

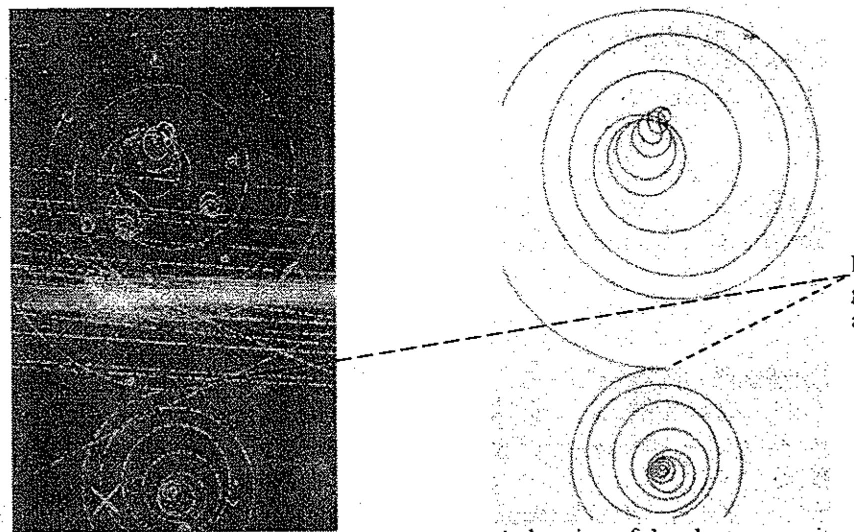
Frequently a **magnetic field** is applied across the chamber, bending the paths of the charged particles. Positive particles are curved in one direction, negative particles in the other. By measuring the curvature of their paths and knowing the strength of the magnetic field, the **charge-to-mass ratio** of the particles can be determined.

Only charged particles and ionizing photons will create tracks in a cloud or bubble chamber. Neither neutral particles nor low-energy photons will be detected.

$$\frac{q}{m} = \frac{v}{BR}$$

When high-energy gamma photons collided with the nuclei within a thin lead plate, electrons and positrons were created simultaneously in a process called **pair production**. In pair production, a photon interacts with a nucleus, the photon ceases to exist, and an **electron-positron pair** is created.

$$\gamma \rightarrow {}^{0}_{+1}e + {}^{0}_{-1}e$$



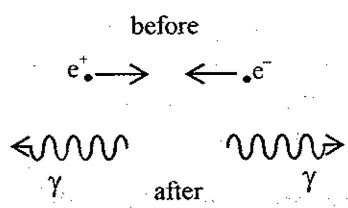
Note that there is no trace of a gamma ray until it collides with a nucleus.

Photograph of electron-positron pair production in a bubble chamber.

A drawing of the electron-positron pair from the photograph. Note that the particles spiral in opposite directions in the external magnetic field.

For electron-positron pair production to occur two things must happen. First, a photon must collide with a nucleus causing the photon's energy to be transformed into particles – i.e. a photon cannot spontaneously decay into a pair. Second, the conservation of mass-energy requires that the minimum photon energy must be equal to the rest mass of an electron plus a positron.

The positron, like the electron, is a stable particle. However, the positron finds itself in the company of zillions (physics technical term meaning "lots") of electrons. Under normal conditions, a positron will collide with an electron within a millionth of a second and they will annihilate (destroy) one another and energy in the form of photons is emitted. This process is known as **pair annihilation,** the direct conversion of mass into electromagnetic energy. Note that two photons are produced. Why? The gamma rays fly off in opposite directions in order to conserve momentum (i.e. zero momentum).



$$e^{+} + e^{-} \rightarrow \gamma + \gamma$$

Since a proton is 1840 times more massive as an electron, the energy required to produce a proton/antiproton pair would have to be 3880 times greater than that of the cosmic rays that produce positrons – i.e. about two thousand million electronvolts (2 GeV)! The production of heavier particles and the need to probe deeper into what matter is made of requires larger and larger accelerators. Today there are accelerators that give particles energies of over 2000 GeV or 2 TeV. The newest and grandest accelerator so far is the Large Hadron Collider (LHD) which will operate at 14 TeV.

Nuclear forces

Soon after the nucleus was discovered there arose an obvious question: Since a group of positively charge particles must repel each other, what holds the nucleus together? A simple calculation of the repulsion between two protons separated by a distance that puts them just about in contact in the nucleus ($\approx 10^{-15}$ m) yields a repulsion value of around 230 N. This is an enormous force when we consider the mass of a proton. By 1925, there was recognition that a new kind of force was needed. The **strong nuclear force** binds neutrons and protons together to form nuclei. It has an effective range of 1.0×10^{-15} m and can have energies of as much as 100 MeV. While the strong force is attractive for distances around 1.0×10^{-15} m, it is repulsive at distances less than 0.5×10^{-15} m (i.e. – two nucleons cannot occupy the same space.)

The strong force, which is the most potent of all interactions, is about 100 times stronger than the electromagnetic force and is 10^{38} times stronger than the gravitational force.

*The Four Forces of Nature**

Force	**Interacts between**	**Relative strength**	**Effective range**	**Mediating particles**	**Particle observed?**
Gravitational	All mass-energy	10^{-34}	Unlimited	gravitons	no
Weak nuclear	All material particles (quarks and leptons)	10^{-2}	$\approx 10^{-17}$ m	W^+, W^-, Z^o	yes
Electromagnetic	Electromagnetic charges	10^{2}	Unlimited	photons	yes
Strong nuclear	Many sub-nuclear particles (quarks and gluons)	10^{4}	$\approx 10^{-15}$ m	gluons	indirectly

*The strengths (in Newtons) are for two protons separated center-to-center, by 2×10^{-15} m.

However, if the strong force is so dominant, why are some nuclei unstable while others are not? There are two reasons for the instability of some nuclei. First, the strong force has a very short effective range. If nucleons become too close the force is repulsive and if they are too far apart the force becomes too weak. The larger the number of nucleons, the greater the distance between the furthest protons in the nucleus. Eventually the distance becomes too large for the strong force to overcome the electrostatic repulsion. The result is the nucleus decaying into smaller nuclei. Second, some nuclei are unstable due to the action of the exotic and destabilizing **weak nuclear force.** This is based on a 1934 theory by Enrico Fermi which explains how neutrons can convert to protons and vice versa. It explains the beta decay of many nuclei.

Quark theory

For the Physics 30 diploma you are required to know:

⇒ Which quarks make up a proton (uud) and a neutron (udd).

⇒ Each quark had a **fractional charge**, either –⅓ or +⅔ of the fundamental electron charge. When the quark charges are added together the result was the observed integer charge of the baryon.

Characteristics of quarks and antiquarks*

	Quarks					Antiquarks			
	Flavour	Symbol	Charge	Spin	Baryon number	Symbol	Charge	Spin	Baryon number
1st generation	Up	u	$+\frac{2}{3}$	$\frac{1}{2}$	$+\frac{1}{3}$	$\bar{u}$	$-\frac{2}{3}$	$\frac{1}{2}$	$-\frac{1}{3}$
	Down	d	$-\frac{1}{3}$	$\frac{1}{2}$	$+\frac{1}{3}$	$\bar{d}$	$+\frac{1}{3}$	$\frac{1}{2}$	$-\frac{1}{3}$
2nd generation	Strange	s	$-\frac{1}{3}$	$\frac{1}{2}$	$+\frac{1}{3}$	$\bar{s}$	$+\frac{1}{3}$	$\frac{1}{2}$	$-\frac{1}{3}$
	Charm	c	$+\frac{2}{3}$	$\frac{1}{2}$	$+\frac{1}{3}$	$\bar{c}$	$-\frac{2}{3}$	$\frac{1}{2}$	$-\frac{1}{3}$
3rd generation	Bottom	b	$-\frac{1}{3}$	$\frac{1}{2}$	$+\frac{1}{3}$	$\bar{b}$	$+\frac{1}{3}$	$\frac{1}{2}$	$-\frac{1}{3}$
	Top	t	$+\frac{2}{3}$	$\frac{1}{2}$	$+\frac{1}{3}$	$\bar{t}$	$-\frac{2}{3}$	$\frac{1}{2}$	$-\frac{1}{3}$

The proton consists of two up quarks and one down quark (uud). The neutron consists of one up quark and two down quarks (udd). We can show that the sum of their charges add up to their observed properties.

For the proton:
charge: (+⅔) + (+⅔) + (–⅓) = +1

For the neutron:
charge: (+⅔) + (–⅓) + (–⅓) = 0

Neutron decay revisited

When physicists determined that the neutron is composed of quarks, one up quark and two down quarks, they realised that the neutron itself was not decaying, but rather one of the quarks was decaying.

The decay of a neutron can also be represented as a quark decay:

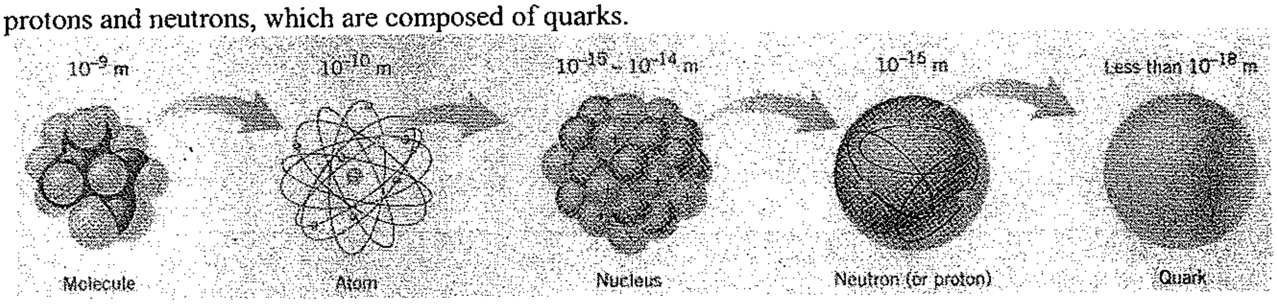
$$udd \longrightarrow uud + e^- + \bar{\nu}_e$$

Similarly, the decay of a proton can also be represented as a quark decay:

$$uud \longrightarrow udd + e^+ + \nu_e$$

The standard model

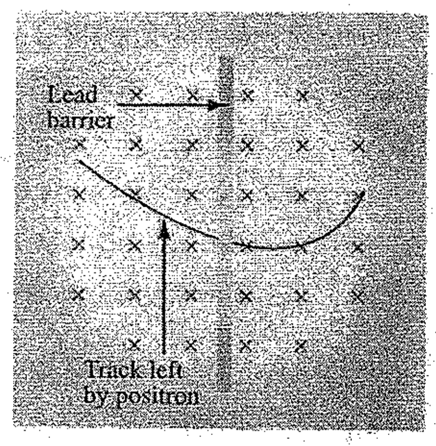
In the standard model, our understanding of the building blocks of matter follows the pattern illustrated in the figure below. Molecules, such as water (H_2O) and glucose ($C_6H_{12}O_6$), are composed of atoms. Each atom consists of a nucleus that is surrounded by a cloud of electrons. The nucleus, in turn, is made up of protons and neutrons, which are composed of quarks.



Use the following information to answer the next question.

The first evidence of antimatter was a photograph of the track produced by a positron as it moved through a perpendicular magnetic field inside a cloud chamber.

An electron moving in one direction through a magnetic field in a cloud chamber leaves a track identical to that of a positron moving in the opposite direction. To prove that a track was made by a positron, scientists conducted an experiment: a thin lead barrier was placed across the path of the particle to slow the particle as it passed through the barrier, thereby revealing the particle's direction of travel. The results of this experiment are illustrated below.



× Represents a magnetic field directed into the page

87. The relative speed of the positron on either side of the barrier is determined by comparing the

A. length of the track on either side of the barrier

B. direction of the curvature on either side of the barrier

C. strength of the magnetic field on either side of the barrier

(D) radius of the curvature of the path on either side of the barrier

curve less if moving faster or if heavier.

88. To study sub-nuclear structure, high-energy particle accelerators are required because

A. plasma exists at high energy

B. antimatter exists at high energy

C. of the short-range effect of the electrostatic force repulsive

(D.) of the short-range effect of the strong nuclear force attractive

accelerators "atom smashers" must break the strong nuclear force in order to break the nucleus.

89. Which of the following decay equations describes beta positive decay?

A. $udd \rightarrow uud + e^- + \bar{\nu}$

B. $udd \rightarrow uud + e^+ + \bar{\nu}$

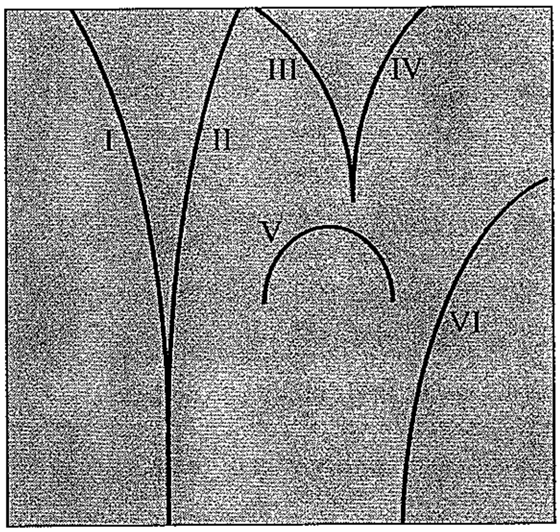
C. $uud \rightarrow udd + e^- + \nu$

D. $uud \rightarrow udd + e^+ + \nu$

proton → neutron + positron
uud udd
$\frac{2}{3}, \frac{2}{3}, -\frac{1}{3}$ $\frac{2}{3}, -\frac{1}{3}, -\frac{1}{3}$

Use the following information to answer the next question.

A high energy gamma ray traveling up the page enters a cloud chamber within a magnetic field. The gamma ray collides with a stationary atom resulting in the formation of two high speed oppositely charged particles.



90. The tracks that would result from the described interaction would be:

A. I and II

B. I and IV

C. III and IV

D. V and VI

pair production

$^{0}_{0}\gamma \rightarrow {}^{0}_{-1}\beta + {}^{0}_{+1}\beta$

particles are highly deflected (small mass) in opposite directions

91. Two types of pions are modelled as consisting of either a down quark and an anti-up antiquark or an up quark and an anti-down antiquark. The only possible charges for these types of pions are

A. $-\frac{2}{3}e$ or $-\frac{1}{3}e$

B. $+\frac{1}{3}e$ or $+\frac{2}{3}e$

C. $-1e$ or $+1e$

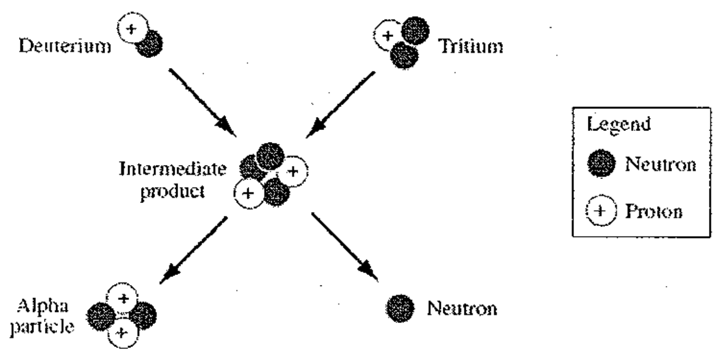
D. $-1e$ or 0

Use the following information to answer the next six questions.

One Solar Nuclear Fusion Reaction Equation

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

Representation of Nuclei Involved in Fusion Reaction



One way to harness this energy on Earth is to use a nuclear fusion reactor. One of the problems in terrestrial fusion reactors is the very high energy required to overcome the electrostatic repulsive force between the deuterium ions and the tritium ions.

A particular reactor design uses magnetic fields in a process called magnetic confinement to keep the ions inside the reactor. However, neutrons escape magnetic confinement. These neutrons are captured by a shield called a lithium blanket.

92. Energy is released in this nuclear fusion reaction because the

A. free neutron has a high energy

B. number of protons remains the same

C. number of nucleons remains the same

D. mass of the alpha particle and neutron is less than the mass of the intermediate product

$F_{el} = \frac{k \cdot q^2}{r^2}$ $R = \sqrt{\frac{k(1.6\times10^{-19})^2}{23.3}}$

Numerical Response

$R = 3.14 \times 10^{-15}$ m

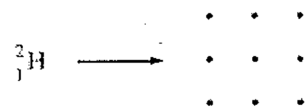
40. At a particular instant, the electrostatic force that the deuterium ion exerts on the tritium ion is 23.3 N. The distance between the centres of the two ions, expressed in scientific notation, is **a.bc** $\times 10^{-w}$ m.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

Use the following additional information to answer the next question.

A positively charged deuterium ion enters a magnetic field directed out of the page, as shown below.

3rd right hand



fingers - out of page
thumb - east
palm - bottom of page.

• Represents a magnetic field directed out of the page

93. The direction of the magnetic deflecting force that acts on the positively charged deuterium ion as it just enters the magnetic field is

A. into the page

B. out of the page

C. toward the top of the page

(D.) toward the bottom of the page

94. The neutron produced in the fusion reaction escapes the magnetic confinement because

(A.) neutral particles are not deflected by magnetic fields

B. the neutron is moving so fast that it escapes the magnetic field

C. the energy produced in the nuclear reaction is enough to cause the neutron to escape

D. conservation of momentum requires that the neutron has to be pushed in the opposite direction to that of the helium produced

95. *As a particular neutron travelling at 5.21 × 10⁶ m/s hits the lithium blanket and stops, it experiences an impulse of __i__ , and the neutron–lithium collision is classified as __ii__ .*

The statements above are completed by the information in row

Row	*i*	*ii*
A.	-8.70×10^{-21} N·s	elastic
B.	-8.70×10^{-21} N·s	inelastic
C.	-2.27×10^{-14} J	elastic
D.	-2.27×10^{-14} J	inelastic

96. Which of the following equations most likely describes a neutron–lithium collision?

A. $^{1}_{0}\text{n} + ^{7}_{3}\text{Li} \rightarrow ^{8}_{3}\text{Li}$

B. $^{1}_{0}\text{n} + ^{4}_{3}\text{Li} \rightarrow ^{5}_{3}\text{Li}$

C. $^{1}_{0}\text{n} + ^{7}_{3}\text{Li} \rightarrow ^{7}_{4}\text{Be}$

D. $^{1}_{0}\text{n} + ^{4}_{3}\text{Li} \rightarrow ^{5}_{4}\text{Be}$

GOOD LUCK ON YOUR EXAM!!!

ANSWERS

Multiple choice

1. D	25. C	49. A	73. C
2. A	26. A	50. C	74. C
3. A	27. D	51. A	75. B
4. B	28. A	52. A	76. C
5. C	29. D	53. D	77. B
6. C	30. B	54. B	78. D
7. A	31. A	55. A	79. C
8. C	32. B	56. D	80. D
9. A	33. D	57. D	81. A
10. D	34. A	58. A	82. D
11. B	35. D	59. B	83. D
12. D	36. C	60. B	84. B
13. B	37. A	61. B	85. B
14. D	38. B	62. B	86. A
15. D	39. B	63. A	87. D
16. C	40. A	64. B	88. D
17. C	41. D	65. D	89. D
18. D	42. D	66. B	90. C
19. A	43. D	67. C	91. C
20. A	44. A	68. B	92. D
21. D	45. D	69. A	93. D
22. D	46. C	70. C	94. A
23. D	47. B	71. C	95. B
24. B	48. C	72. D	96. A

Numerical Response

1. 401	25. 5 4(±1) 3 7(±1)
2. 3141	26. 5827 or 5877
3. 4641	27. 132
4. 5007	28. 1994
5. 780	29. 6213
6. 9445	30. 1819
7. 8407	31. 1715
8. 1718 or 1818	32. 122
9. 6.94	33. 59 or 29
10. 21 or 51	34. 318
11. 6412	35. 179
12. 9.29	36. 2346
13. 3875	37. 12.5
14. 9305	38. 2.5
15. 3124	39. 736
16. 1.60	40. 3.14
17. 36	
18. 5014	
19. 24.6	
20. 1263	
21. 5833	
22. 1812	
23. 2942	
24. 8618	