Chapter 1 :

Units and Dimension

1. Physical quantities
2. Units
3. Conversion of units
4. Dimension analysis

Physics is a Greek word whose origin means knowledge of nature. It is a science that research to study the universe with its material, energy and their interactions, and the resulting recurring phenomena. The main objectives of physics are to identify a limited number of fundamental laws that govern natural phenomena and use them to develop theories that can predict the results of future experiments. Everything we know about this universe and the laws that govern it are reached through measurements and observations of natural phenomena.

1. Physical quantities

Physical quantities used to create the main structure of Physics, it might be used in case of find out the laws and equation that related to physic, and can be divided to two types as following:

Fundamental quantities

They are not expressed in terms of other physical quantities, and are known only by themselves. these quantities are length, mass, time, electric current intensity, temperature, intensity of illumination, and amount of matter.

Derived quantities

They are defined in terms of the fundamental physical quantities, these derived quantities such as volume, velocity, density, acceleration, energy, power, and other quantities.

2. Units

Any physical quantity must have a unit of measurement in addition to its numerical value, as it makes no sense to say that the distance between the city of Bisha and the city of Abha is 300 (without mentioning the unit of measurement), because 300 kilometres differ from 300 meters and differ from 300 miles, as the kilometres, meters, and miles are units of measure of length. In this section, we will be concerned with International system of units (SI) for measuring physical quantities.

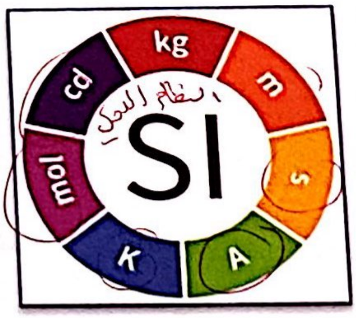

Figure 1.1: International System of Units (SI).

Table (1.1): Prefixes for Powers of Ten.

Abbreviation	Prefix	Power
n	nano-	10^{-9}
μ	micro-	10^{-6}
m	milli-	10^{-3}
c	centi-	10^{-2}
d	deci-	10^{-1}
da	deka-	10^{1}
k	kilo-	10^{3}
M	mega-	10^{6}
G	giga-	10^{9}

Example: 1.1

On the side board of the road, the maximum average speed s was found as $90\,\frac{km}{h}$, convert this value to speed with $\frac{m}{s}$ units.

Solution

$$s = 90\,\frac{km}{hr}$$

$$= 90\,\frac{10^3}{3600}\frac{m}{s} = 25\,\frac{m}{s}$$

Example: 1.2

How much mercury density is ρ in SI unit system, if it is equal to $13.6\,\frac{g}{cm^3}$?

Solution

$$\rho = 13.6\,\frac{g}{cm^3}$$

$$= 13.6\,\frac{10^{-3}}{(10^{-2})^3}\frac{kg}{m^3} = 1.36 \times 10^4\,\frac{kg}{m^3}$$

Unit of amount of substance (mole - mol)

The mole is the amount of substance in a system that contains a number of elementary units equal to the number of 12 gram of carbon-12 atoms, and these primary units can be atoms, molecules, ions, or it is a specific group that includes all of these types.

3. Converting units

Perhaps, to solve problems, units from small units must be converted into large units or vice versa in the same system, or from one system to another system. Unit conversion is the first step to solving problems in order to standardize units. As the minute is divide to the 60 seconds, we can write the following conversion equation:

$$1\ \text{min} = 60\ s$$

above equation can apply to convert from minutes to seconds and vice versa, for example, converting 3 minutes to seconds by multiplying both sides of the previous equation by 3, thus obtaining:

$$3\ \text{min} = 180\ s$$

Based on that, the conversion coefficient from minutes to seconds will be 60, while the conversion coefficient from seconds to minutes become $\frac{1}{60}$ according to the conversion equation:

$$1\,s = \frac{1}{60}\ \text{min}$$

Thus, for the rest of the units, Table 1.1 shows conversion coefficients for some units.

Unit of lengths (meters - m)

The meter (m) is defined as the length of distance travelled by light in a vacuum in a time period equal to $\frac{1}{299792458}$ s.

Unit of mass (kilogram - kg)

Figure 1.2: A kilogram kept in the International Bureau of Scales and Measures, Paris.

The kilogram (kg) is defined as the mass of a specific platinum–iridium alloy cylinder as shown in Figure 1.2, and this cylinder is kept at the International Bureau of Weights and Measures at Paris, France.

Unit of time (second - s)

The second (s) is now defined as 9192631770 times the period of vibration of radiation from the cesium-133 atom.

Unit of temperature (Kelvin - K)

The Kelvin (K) is defined to be $\frac{1}{273.16}$ of the difference between absolute zero and the temperature of the triple point of water.

Unit of electric current (Ampere - A)

The Ampere (A) is equivalent to 1 Coulomb of charge passing through a surface in 1 second.

Unit of luminous intensity (candle - cd)

The candela is the luminous intensity, in a given direction, of a light source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of $\frac{1}{683}$ watt per steradian.

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Figure 1.1: International System of Units (SI).

$\beta = 0$

$$T = c\, L^{\frac{1}{2}} m^{0} g^{-\frac{1}{2}}$$

$$= c\sqrt{\frac{l}{g}}$$

In practice, the constant C was equal to 2π:

$$T = 2\pi\sqrt{\frac{l}{g}}$$

Exercises

1. If you know that the gravitational acceleration is 9.8 $\frac{m}{s^2}$, calculate its value in $\frac{cm}{s^2}$.

2. Use dimensional theory to prove the ideal gas equation:

$$PV = nR\,T,$$

where V is the volume, P is the pressure, and T is the temperature and n are number of moles, knowing that R is a constant.

3. Find the following dimensions of the physical constants: (general attraction constant (G) - Planck constant (h) - viscosity coefficient (η)) if you know that these constants are given by the following relationships, respectively:

$$F = 6\pi\,\eta\,v\,r,$$

$$E = h\,\nu,$$

$$F = G\,\frac{m_1\,m_2}{r^2}.$$

4. Verify the following relationship using dimensional theory:

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

5. Using the dimensional theory, deduce the Einstein's equation, which linked the relationship between body mass, speed of light, and energy.

6. Find the force $F = 50\ \frac{m\ g}{s^2}$ in the international system units SI.

7. Find out the area of a square box in meters (m) if its side is 20 cm.

8. A cube of iron with a mass of 856 g and a length of each side equal 5.32cm. Calculate the density of the cube ρ in units of SI.

4. Dimensional theory

Let's focus our discussion on classical mechanics. The Dimension of any a physical quantity is determined the nature of this quantity, whether it is Mass, Length, or Time. The dimensions of any physical quantity are written in terms of mass [M], length [L] and time [T]. Dimensional theory states that homogeneity must be in each side of mathematical equations.

The importance of the dimensional theory is in the following:

a. Validation of physical laws.
b. Easily derive some physical laws.
c. Derive the units of the constants on which the physical relationship depends.

Table (1.2) shows the dimensions of some physical quantities.

Physical Quantity	Dimensions
$density\ (\rho) = \frac{mass}{volume}$	$[\rho] = \frac{M}{L^3} = ML^{-3}$
$velocity(v) = \frac{displacement}{time}$	$[v] = \frac{L}{T} = LT^{-1}$
$accelaration\ (a) = \frac{velocity}{time}$	$[a] = \frac{LT^{-1}}{T} = LT^{-2}$
$force\ (F) = mass\ .accelaration$	$[F] = M \times LT^{-2} = MLT^{-2}$
$work\ (W) = force\ .displacement$	$[W] = MLT^{-2} \times L = ML^2T^{-2}$
$power\ (P) = \frac{work}{time}$	$[P] = \frac{M \times L^2T^{-2}}{T} = ML^2T^{-3}$

Example: 1.3

Verify the validity of the simple pendulum formula: $T = 2\pi\sqrt{\frac{L}{g}}$,where T is the periodic time, L is the length of the pendulum thread, and g is the gravitational acceleration.

Solution

The left side dimension of the equation: $[T]$

The right-side dimension of the equation: $\sqrt{\frac{[L]}{[LT^{2}]}} = [T]$

So, this equation is dimensionally homogeneous. It is correct.

Example: 1.4

Using dimensional theory, derive the relationship between the periodic time of a simple pendulum, the length of a thread, the mass of the sphere, and the gravitational acceleration.

Solution

$$T = f\,(l.m.g)$$
$$= c\, l^{\alpha} m^{\beta} g^{\gamma}$$

Where c is a constant of proportionality and we use dimensional theory to designate the three constants α, β, γ.

$$[T] = [L]^{\alpha}[M]^{\beta}[LT^{-2}]^{\gamma}$$
$$= L^{\alpha} M^{\beta} L^{\gamma} T^{-2\gamma}$$
$$= L^{\alpha+\gamma} M^{\beta} T^{-2\gamma}$$

$$-2\gamma = 1 \quad \rightarrow \quad \gamma = -\frac{1}{2}$$

$$\alpha + \gamma = 0 \quad \rightarrow \quad \alpha = \frac{1}{2}$$

1. Scalar and vector quantities

Scalar quantities

Scalar quantities are the physical quantities that can be defined by knowing its magnitude only, such as distance, mass, time...

Vector quantities

Vector quantities are the physical quantities that can be defined by knowing their magnitude and direction, such as displacement, Velocity, acceleration, and force ...

To explain the difference between the scalar and vector quantities, we assume that a man moves his home away from the mosque by 30 m, as in Figure (2.1), and the man travels it back and forth whenever he intends to pray, this distance is fixed and completely defined by knowing its amount only, and the distance between the mosque and the house will not change if he is going or returning from it.

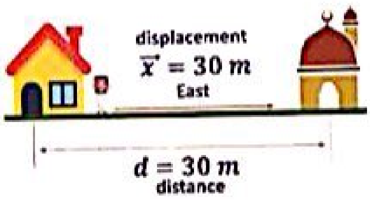


Figure 2.1: The difference between scalar and vector quantities

When we talked about the displacement vector, we say that if a man goes to the mosque, he turns east toward the mosque with displacement of 30 m, and this vector is completely different from the displacement vector when he goes back from the mosque to the house, where the man moves to his house in the direction of the west by 30 m. So, the displacement vector is completely determined by knowing the magnitude and direction of this vector.

2. Vectors addition

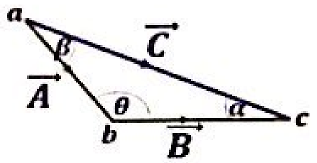


Figure 2.2: Vectors addition

Assume that an object is displaced from point "a" to "b" across the vector $\vec{A}$ and then from point "b" to "c" across the vector $\vec{B}$, as shown in Figure (2.2). The resultant is the displacement of the object from "a" to "c" via the vector $\vec{C}$, what we call the summation of the two vectors:

$$\vec{C} = \vec{A} + \vec{B}$$

The magnitude of vector C can be found by the cosine rule:

$$C = \sqrt{A^2 + B^2 - 2AB\cos\theta}$$

While its direction can be determined by sine rule:

$$\frac{\sin\alpha}{A} = \frac{\sin\beta}{B} = \frac{\sin\theta}{C}$$

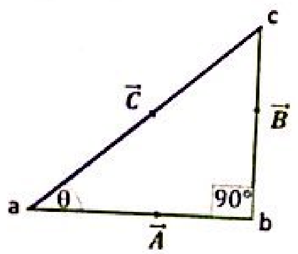


Figure 2.3: Vectors addition (right triangle)

The magnitude of vector C in right triangle can be found by Pythagoras theorem:

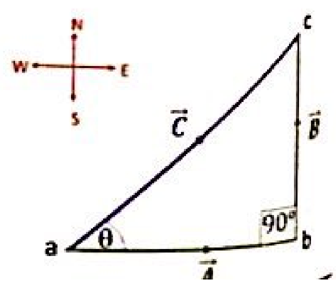
$$C = \sqrt{A^2 + B^2}$$

The direction of vector C can be determined by angle θ:

$$\theta = \tan^{-1}\frac{B}{A}$$

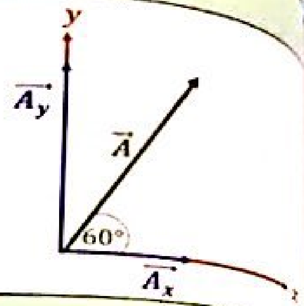
Example: 2.1

Find the sum of two vectors of $\vec{A} = 4$ in East and $\vec{B} = 4$ in North.



Example: 2.3

Vector $\vec{A}$ is 3 cm and makes an angle of 60° with the positive x axis, find the two components of this vector.



Solution

$\vec{A_x} = A\cos\theta\,\hat{\imath}$

$= 3\cos 60\,\hat{\imath} = 1.5\,\hat{\imath}$

$\vec{A_y} = A\sin\theta\,\hat{\jmath}$

$= 3\sin 60\,\hat{\jmath} = 2.6\,\hat{\jmath}$

We can add two vectors in the form of analytical compounds by equations:

$$\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath} + A_z\hat{k}$$

$$\vec{B} = B_x\hat{\imath} + B_y\hat{\jmath} + B_z\hat{k}$$

$$\vec{A} + \vec{B} = (A_x + B_x)\hat{\imath} + (A_y + B_y)\hat{\jmath} + (A_z + B_z)\hat{k}$$

Example: 2.4

Find the resultant vector $\vec{C}$, which is the sum of the two vectors:

$$\vec{A} = 4\hat{\imath} + 6\hat{\jmath} + 2\hat{k}, \qquad \vec{B} = 3\hat{\imath} + 3\hat{\jmath} - 2\hat{k},$$

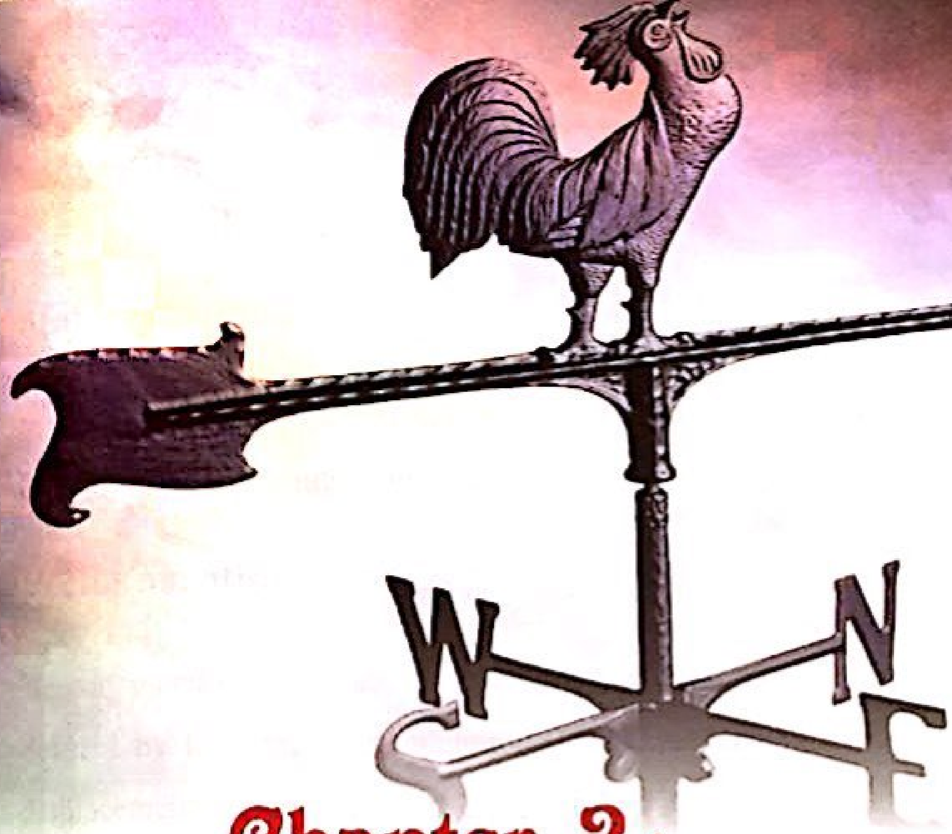
Solution

$\vec{C} = \vec{A} + \vec{B}$

$= (A_x + B_x)\hat{\imath} + (A_y + B_y)\hat{\jmath} + (A_z + B_z)\hat{k}$

$= (4+3)\hat{\imath} + (6+3)\hat{\jmath} + (2-2)\hat{k}$

$= 7\hat{\imath} + 9\hat{\jmath}$



Chapter 2:

Vectors

1. Scalar and vector quantities
2. Vectors addition
3. Vectors analysis
4. Vectors product

Physics deals with a lot of quantities that have a magnitude and direction, so you need a special mathematical language called a vector to describe these quantities. This language is also used in engineering and other sciences and even in general speech, if you have previously given directions such as how to get to the mosque in the neighborhood where you live, go east 100 meters and then go right 10 meters and find the mosque to your left, In this case we have used here the vector language. In this chapter, we will study some of the vector propertiesn, addition, analysis, and product.

3. Vectors analysis

Figure (2.9) shows the vector $\vec{A}$ make an angle θ with the horizontal axis x, this vector can be analyzed to two vectors. The vector ($\vec{A}_x$) in the direction of the horizontal axis x is called the horizontal component. As well as, the vector ($\vec{A}_y$) in the direction of the vertical axis y is called the vertical component.

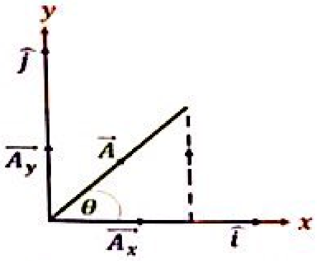


Figure 2.9: Vector analysis.

$$\vec{A} = \vec{A}_x + \vec{A}_y$$

We use unit vectors ($\hat{\imath}$. $\hat{\jmath}$. $\hat{k}$) to denote the direction of the axes (x.y.z), respectively, as shown in Figure (2.10). We call this system a right-hand coordinate system, meaning that it applies the right-hand system. We write the vector $\vec{A}$ in the Cartesian coordinate system on the image.

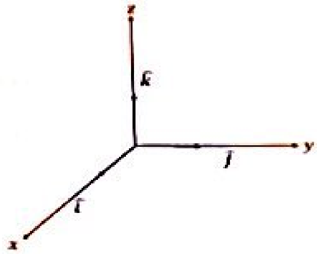


Figure 2.10: Unit vectors in Cartesian coordinates.

$$\vec{A} = A_x \hat{\imath} + A_y \hat{\jmath}$$

The magnitude of the two compounds can be calculated from the rule of the triangle as following:

$$A_x = A \cos \theta$$

$$A_y = A \sin \theta$$

The vector $\vec{A}$ can be written as following:

$$\vec{A} = A \cos\theta \, \hat{\imath} + A \sin\theta \, \hat{\jmath}$$

9. The mass of the proton is $1.6 \times 10^{-27} kg$ and the electron mass is $9.1 \times 10^{-31} kg$, how much these masses are equal to grams (g).

10. If you know that an electrical conductor has a charge of $1.6 \times 10^{-9} \mu C$, how much is this charge in colum units (C).

Solution

$C = \sqrt{A^2 + B^2}$

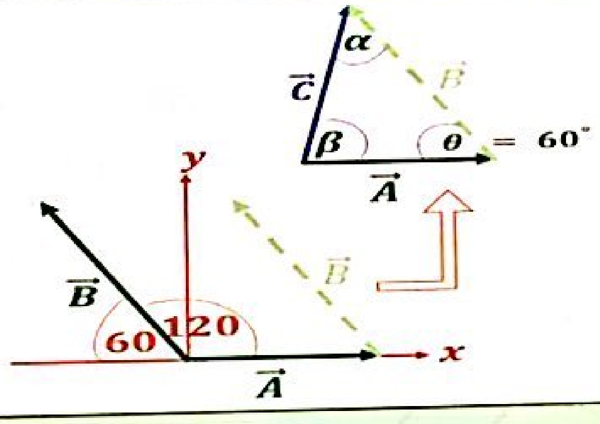
$= \sqrt{4^2 + 4^2} = 5.7$

$\theta = tan^{-1}\frac{B}{A}$

$= tan^{-1}\frac{4}{4} = 45^\circ$

Example: 2.2

Two vectors, $\vec{A} = 6$ and $\vec{B} = 9$.
Calculate their resultant $\vec{C}$.



Solution

First: Re-draw the vector $\vec{B}$ as shown above, then find out the resultant vector $\vec{C}$.

$C = \sqrt{A^2 + B^2 - 2AB\cos\theta}$

$= \sqrt{6^2 + 9^2 - 2 \times 6 \times 9 \times \cos 60} = 7.9$

Second: Calculate the direction of resultant vector by sine rule

$\frac{\sin\beta}{B} = \frac{\sin\theta}{C}$

$\beta = \sin^{-1}\left(\frac{B}{C}\sin\theta\right)$

$= sin^{-1}\left(\frac{9}{7.9} * sin\ 60\right) = 80.6^\circ$

Properties of vectors

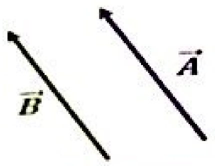


Figure 2.4: Vectors equality.

- The two vectors $\vec{A}$ and $\vec{B}$ are equal when they have the same magnitude and the same direction, as shown in Figure (2.4):

$$\vec{A} = \vec{B}$$

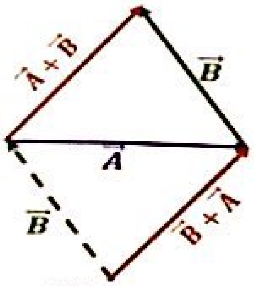


Figure 2.5: The Commutative property.

- The vectors addition process is a commutative, as shown in Figure (2.5):

$$\vec{A} + \vec{B} = \vec{B} + \vec{A}$$

- The vectors addition process is a associative (you can try to prove it):

$$(\vec{A} + \vec{B}) + \vec{C} = \vec{A} + (\vec{B} + \vec{C})$$

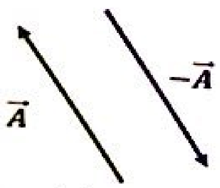


Figure 2.6: Inverse of the vector.

- The inverse summation of vector $\vec{A}$ is a vector with the same magnitude of vector $\vec{A}$ but in the opposite direction, as shown in Figure (2.6):

$$\vec{A} + (-\vec{A}) = 0$$

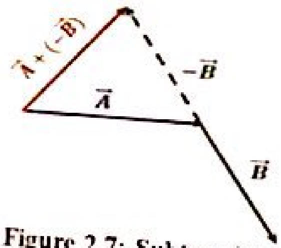


Figure 2.7: Subtraction of vectors.

- We use the inverse of the vector in the vector's subtraction process, as shown in Figure (2.7).

$$\vec{C} = \vec{A} - \vec{B} = \vec{A} + (-\vec{B})$$

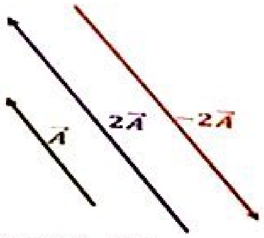


Figure 2-8: Multiplying the vector by a constant amount.

- when multiply the vector $\vec{A}$ by the scalar n, we get a new vector $\vec{B} = n\,\vec{A}$ of value nA. This vector $\vec{B}$ is in the same direction as vector $\vec{A}$ if n is positive, and it is in the opposite direction of vector $\vec{A}$ if n is negative, as shown in the Figure (2.8).

$$\hat{\imath}\cdot\hat{\imath}=1\,. \qquad \hat{\jmath}\cdot\hat{\jmath}=1\,. \qquad \hat{k}\cdot\hat{k}=1$$

$$\hat{\imath}\cdot\hat{\jmath}=0\,. \qquad \hat{\jmath}\cdot\hat{k}=0. \qquad \hat{k}\cdot\hat{\imath}=0$$

When the two vectors are in the form of compounds, the scalar product is:

$$\vec{A}=A_x\hat{\imath}+A_y\hat{\jmath}+A_z\hat{k}$$

$$\vec{B}=B_x\hat{\imath}+B_y\hat{\jmath}+B_z\hat{k}$$

$$\vec{A}\cdot\vec{B}=A_xB_x+A_yB_y+A_zB_z$$

To find the angle between the two vectors, we use the relationship:

$$\cos\theta=\frac{\vec{A}\cdot\vec{B}}{AB}$$

Example: 2.6

Find the standard product of the following two vectors:

$$\vec{A}=20\hat{\imath}+10\hat{\jmath} \quad \text{and} \quad \vec{B}=6\hat{\imath}+2\hat{\jmath}$$

Solution

$$\vec{A}\cdot\vec{B}=A_xB_x+A_yB_y$$
$$=(20\times 6)+(10\times 2)=140$$

Example: 2.7

Find out the angle between the following two vectors:

$$\vec{A}=2\hat{\imath}+2\hat{\jmath}-\hat{k} \quad \text{and} \quad \vec{B}=6\hat{\imath}+3\hat{\jmath}+2\hat{k}$$

Solution

Example: 2.8

Find the vector product of two vectors $|A| = 100$ and $|B| = 20$, with an angle between them is 60 °.

Solution

$$\vec{A} \times \vec{B} = A\,B\sin\theta\,\hat{n}$$

$$= 100 \times 20 \times \sin 60 = 1732\,\hat{n}$$

If the two vectors are parallel θ = 0°, then their directional multiplication result is zero. As for the unit vectors of the Cartesian axes, they have the following characteristics:

$$\hat{\imath} x \hat{\imath} = 0. \qquad \hat{\jmath} x \hat{\jmath} = 0. \qquad \hat{k} x \hat{k} = 0$$

$$\hat{\imath} x\, \hat{\jmath} = -\hat{\jmath} x \hat{\imath} = \hat{k}\,. \qquad \hat{\jmath} x\, \hat{k} = -\hat{k} x \hat{\jmath} = \hat{\imath}. \qquad \hat{k} x \hat{\imath} = -\hat{\imath} x \hat{k} = \hat{\jmath}$$

When the vectors are in the analytical form, the vector product is calculated from the following matrix:

$$\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath} + A_z\hat{k}$$

$$\vec{B} = B_x\hat{\imath} + B_y\hat{\jmath} + B_z\hat{k}$$

$$\vec{A} x \vec{B} = \begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$$

$$\vec{A} x \vec{B} = \hat{\imath}\begin{vmatrix} A_y & A_z \\ B_y & B_z \end{vmatrix} - \hat{\jmath}\begin{vmatrix} A_x & A_z \\ B_x & B_z \end{vmatrix} + \hat{k}\begin{vmatrix} A_x & A_y \\ B_x & B_y \end{vmatrix}$$

$$= \hat{\imath}(A_yB_z - A_zB_y) - \hat{\jmath}(A_xB_z - A_zB_x) + \hat{k}(A_xB_y - A_yB_x)$$

4. Vectors product

There are two types of vectors product, the first one known as the scalar product, while the other one known as the vector product.

Scalar product

Assume that we have two vectors $\vec{A}$ and $\vec{B}$ with an angle θ as in the Figure (2.11), then their scalar product is calculated from:

$$\vec{A} \cdot \vec{B} = AB\cos\theta$$

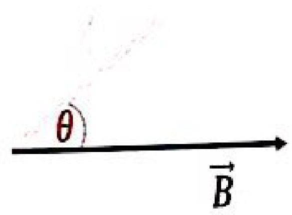


Figure 2.11: Scalar product of vectors.

We note that the angle between the two vectors is the angle between them when they initiate from one point. The product of the scalar product is a scalar quantity and not a vector. The scalar product is a commutative.

$$\vec{A} \cdot \vec{B} = \vec{B} \cdot \vec{A}$$

Example: 2.5

Find the scalar product of the two vectors $|A| = 100$ and $|B| = 20$, with an angle between them is 60 °.

Solution

$$\vec{A} \cdot \vec{B} = AB\cos\theta$$

$$= 100 \times 20 \times \cos 60 = 1000$$

If the two vectors are orthogonal θ = 90, then their scalar product is zero, and for the unit vectors of the Cartesian axes, they have the following properties:

$$\cos\theta = \frac{\vec{A}\cdot\vec{B}}{A\,B}$$

$$\vec{A}\cdot\vec{B} = (2\times 6) + (2\times 3) + (-1\times 2) = 16$$

$$A = \sqrt{(2)^2 + (2)^2 + (-1)^2} = 3$$

$$B = \sqrt{(6)^2 + (3)^2 + (2)^2} = 7$$

$$\theta = \cos^{-1}\frac{\vec{A}\cdot\vec{B}}{A\,B}$$
$$= \cos^{-1}\frac{16}{3\times 7} = 40.1^{\circ}$$

Vector product

Suppose we have two vectors $\vec{A}$ and $\vec{B}$ with an angle θ as in Figure (2.12), then their vector product is calculated from the relationship:

$$\vec{C} = \vec{A}\times\vec{B} = AB\sin\theta\,\hat{n}$$

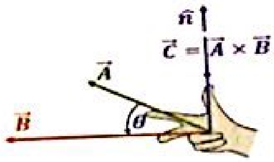


Figure 2.12: Directional multiplication

We note that the angle between the two vectors is the angle between them when they initiate from the same point. The resultant vector $\vec{C}$ is perpendicular on both vectors $\vec{A}$ and $\vec{B}$. vector $\vec{C}$ indicates by unit vector $\hat{n}$ according to the right hand rule as shown in Figure (2.12), so that vector $\vec{A}$ is the thumb while the vector $\vec{B}$ is represented by the index finger, and the middle is the direction of the third vector $\vec{C}$. Also, the vector product process is not a commutative process:

$$\vec{A}\times\vec{B} = -\vec{B}\times\vec{A}$$

b. $|A| = 4\,m, \quad \theta = 150°$

c. $|A| = 10\,m, \quad \theta = 235°$

7. If we have two vectors $\vec{A} = 2\hat{\imath} + 2\hat{\jmath}$ and $\vec{B} = 4\hat{\imath} + 4\hat{\jmath}$, Calculate the following:

   a. $\vec{A} \cdot \vec{B}$

   b. Angle θ between two vectors.

   c. Vector C in which $\vec{C} = \vec{A} + 2\vec{B}$

8. Find the vector product of two vectors |A| = 50 and |B| = 20, with an angle between them is 45°.

9. Prove that the two vectors $\vec{A} = 3\hat{\imath} + 3\hat{\jmath} + 3\hat{k}$ and $\vec{B} = 2\hat{\imath} + \hat{\jmath} - 3\hat{k}$ are orthogonal.

10. Find the vector product of two vectors $\vec{A} = 3\hat{\imath} - 4\hat{\jmath} + 2\hat{k}$ and $\vec{B} = -2\hat{\imath} + 3\hat{\jmath} + 3\hat{k}$

Chapter 3:

Motion in one dimension

1. Displacement
2. Velocity
3. Acceleration
4. Motion with constant acceleration

Motion of objectsare one of the most important physical phenomena, in which we must understand its basic principles. These simple principles have enabled us to predict the motion of objectsand know the causes of their movement. The science that examines the motion of objects and their static is called mechanics, and the study of this science is an excellent start to the study of physics, because of the clarity of experiments. In this section, we will learn about the concept of displacement, velocity and acceleration.

Example: 2.9

Find the vector product of two vectors:

$$\vec{A} = 3\hat{\imath} - 4\hat{\jmath} \quad \text{and} \quad \vec{B} = -2\hat{\imath} + 3\hat{\jmath}$$

Solution

$$\vec{A} \times \vec{B} = \begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ 3 & -4 & 0 \\ -2 & 3 & 0 \end{vmatrix}$$

$$= [(3 \times 3) + (-4 \times -2)]\hat{k}$$

$$= 17\ \hat{k}$$

Exercises

1. Vector $\vec{A}$ is 10 units in positive x-axis direction and, Vector $\vec{B}$ is 7 units and its direction make an angle of 30° from x-axis direction, find the resultant vectors of the summation of the two vectors $|\vec{A}+\vec{B}|$.

2. Point P have Cartesian coordinates as (-2, -4) located in the level (x, y). Draw this point.

3. If $\vec{A}$ represents a displacement of 3m with a direction making 30° with the positive horizontal direction of the x-axis, while the vector $\vec{B}$ represents other distance of 3m with a positive direction of the y-axis. Find the following:

   a. $\vec{A}+\vec{B}$
   b. $\vec{A}-\vec{B}$
   c. $\vec{B}-\vec{A}$
   d. $3\vec{A}-\vec{B}$

4. If you have two vectors the first have the magnitude A = 6 units and makes an angle of 36 ° with the positive horizontal axis x and the second vector of B = 7 units along the negative horizontal axis x. Find the following:

   a. $\vec{A}+\vec{B}$
   b. $\vec{A}-\vec{B}$

5. Find the vector $\overrightarrow{AB}$ that connect between the point A (2,1) and point B (-1, 2)

6. If the vector $\vec{A}$ makes an angle of θ with the positive horizontal direction of the x-axis. Find the compounds of vector $\vec{A}$ in the following cases:

   a. $|A| = 6\,m, \quad \theta = \quad 60°$

In our practical life we also deal with concept of average speed, which is defined as the rate of change of distance d with respect to time, the average speed is a scalar quantity. For example, the amount of average speed that appears on the car speedometer and is calculated from:

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

Where d is the distance travelled during the time period Δt.

Instantaneous velocity

The instantaneous velocity $\vec{v}_x$ is defined as the limit of the average velocity $\vec{v}_{av}$ as Δt approaches zero:

$$\vec{v}_x = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt} \tag{3.3}$$

Example: 3.2

The position of a vehicle moving in a straight line according to the following relationship:

$$x(t) = 6t^2 - t + 1$$

Where x is measured in meters and t in seconds. Calculate:

a. The position at the moment t = 0 s.
b. The position at the moment t = 3 s.
c. The displacement of vehicle during this time period.
d. Instantaneous velocity at moment t = 0 s.
e. Instantaneous velocity at moment t = 3 s.
f. The average velocity during this time period.

Solution

a. The position at the moment t = 0s.

$$x(t=0) = 6 \times 0^2 - 0 + 1 = 1\ m$$

b. The position at the moment t = 3 s.

$$x(t=3) = 6 \times 3^2 - 3 + 1 = 52\ m$$

c. The displacement of vehicle during this time period.

$$\Delta\vec{x} = x_2 - x_1$$
$$= 52 - 1 = 51$$

d. Instantaneous velocity at moment t = 0 s.

$$v_x = \frac{d\vec{x}}{dt} = 12t - 1$$

$$v_x(t=0) = 12 \times 0 - 1 = -1\ \frac{m}{s}$$

e. Instantaneous velocity at moment t = 3 s.

$$v_x(t=3) = 12 \times 3 - 1 = 35\ \frac{m}{s}$$

f. The average velocity during this time period.

$$\vec{v}_{av} = \frac{\Delta\vec{x}}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1}$$
$$= \frac{51}{3} = 17\ \frac{m}{s}$$

1. Displacement

Displacement is defined as the change in the position of an object relative to a reference point. It is a vector quantity and depends on the starting and ending points, meaning that the path the body follows between the two points has no effect on displacement.

The displacement differs from the distance, where the distance represents the actual length of the path the body is taking, which is a scalar quantity, while the displacement represents the shortest distance connecting the two points. Assume an object moving from point A to point B through the ACDEFB path shown in Figure 3.1. The amount of the displacement vector ($\overrightarrow{AB}$) represent the shortest distance between the starting and ending points of movement and equal to 10 m while the direction of the displacement vector is in the positive direction of the x-axis. The distance between points A and B across the ACDEFB motion path represents the sum of the distances traveled between the two points and equal to 17.5 m.

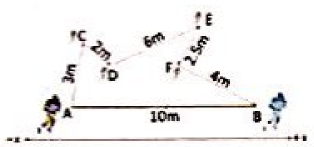


Figure 3.1: Different between distance and displacement

Suppose an object whose position changed from x_1 at time t_1 to x_2 at time t_2, then the displacement is:

$$\Delta\vec{x} = x_2 - x_1 \quad (3.1)$$

Example: 3.1

A group of runners set off from the starting point O towards point A, which is located 1320 m east. From point A, runners head towards point B, which is 940 m west, then to point C, 320 m east, as shown in the figure. Determine the displacement between the starting point and the ending point C, and the distance travelled between them?

Solution

The distance OC:

$$OC = OA - AB + BC$$

$$= 1320 - 940 + 320 = 700m$$

The displacement between the starting point O and the end point C is:

$$\Delta\vec{x} = x_C - x_O$$
$$= 700 - 0 = 700m$$

The traveled distance is the actual length of the total traveled path, which is:

$$d = 1320 + 940 + 320 = 2580m$$

2. Velocity

Average velocity

Suppose an object whose position changed from x_1 at time t_1 to x_2 at time t_2. We know the average velocity as the rate of change of displacement relative to time, which is a vector and has the same direction of displacement.

$$\vec{v}_{av} = \frac{\Delta\vec{x}}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1} \tag{3.2}$$

Where x_0 is the position of the object at the beginning of the movement, i.e. at $t = 0$. The last equation links the three variables (a, t, x). Another equation that relates variables (x, v, a) can be deduced by using the definition of acceleration to infer time, then offset time in the position equation:

$$a = \frac{v_f - v_i}{t} \to t = \frac{v_f - v_i}{a}$$

$$x_f = x_i + v_i t + \frac{1}{2}at^2$$

$$= x_i + v_i\frac{v_f - v_i}{a} + \frac{1}{2}a\left(\frac{v_f - v_i}{a}\right)^2$$

$$(x_f - x_i)a = v_f(v_f - v_i) + \frac{1}{2}(v_f - v_i)^2$$

$$= v_f v_i - v_i^2 + \frac{1}{2}(v_f^2 + v_i^2 - 2v_f v_i)$$

$$(x_f - x_i)a = \frac{1}{2}(v_f^2 + v_i^2)$$

$$v_f^2 = v_i^2 + 2a(x_f - x_i)$$

$$= v_i^2 + 2a\Delta x$$

So, we have three equations for linear motion with a constant acceleration, which are:

$$v_f = at + v_i \qquad (3.6)$$

$$x_f = \frac{1}{2}at^2 + v_i t + x_i \qquad (3.7)$$

$$v_f^2 = v_i^2 + 2a\Delta x \qquad (3.8)$$

Example: 3.4

A car moving from static on a straight line with a constant acceleration of $2.5\,\frac{m}{s^2}$, calculate the following:

a. The time needed to travel 50 m.

b. The velocity of the car at the end of this period.

Solution

a. The car moves from static with initial velocity equal zero. The time required to travel a 50 m distance can be calculated from:

$$x_f = \frac{1}{2}at^2 + v_i t + x_i$$

$$50 = \frac{1}{2} \times 2.5 \times t^2$$

$$t^2 = \frac{50}{1.25} = 40s^2$$

$$t = \sqrt{40} = 6.32s$$

b. To find the vehicle velocity after a time of 6.32 s:

$$v_f^2 = v_i^2 + 2a\Delta x$$

$$= 2 \times 2.5 \times 50 = 250$$

$$v = 15.81\,\frac{m}{s}$$

Freely Falling Objects

If we throw an object up or down while neglecting the wind resistance, we find that the object is accelerating downward

Solution

$$\vec{v}_x = \frac{d\vec{x}}{dt} = 6t^2 - 6t + 2$$

$$\vec{a}_x = \frac{d\vec{v}}{dt} = 12t - 6$$

$$a_x(t = 3) = 12 \times 3 - 6 = 30\frac{m}{s^2}$$

4. Motion with constant acceleration

If an object moves at an increasing or decreasing velocity and with a constant rate and direction, the motion of the object is at a constant acceleration. Suppose that the velocity of an object at the start of movement, that is at time $t_i = 0\ s$ is v_i. The velocity of the object becomes v_f at time t_f, the acceleration of an object can be written as

$$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i} = \frac{v - v_0}{t}$$

By this formula the object will move at an initial velocity v_i with a constant acceleration a:

$$v_f = at + v_i$$

While their position can calculate from:

$$x_f = \int v dt = \int (at + v_i) dt$$

$$x_f = \frac{1}{2}at^2 + v_i t + x_0$$

3. Acceleration

Average acceleration

When the velocity of the particle changes from $\vec{v}_1$ at time t_1 to $\vec{v}_2$ at time t_2, the average acceleration $\vec{a}_{av}$ is defined as the rate of velocity change in time.

$$\vec{a}_{av} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_2 - \vec{v}_1}{t_2 - t_1} \qquad (3.4)$$

Instantaneous acceleration

The instantaneous acceleration $\vec{a}_x$ is defined as the limiting value of the ratio $\frac{\Delta\vec{v}}{\Delta t}$ as Δt approaches zero:

$$\vec{a}_x = \lim_{\Delta t\to 0}\frac{\Delta\vec{v}}{\Delta t} = \frac{d\vec{v}}{dt} \qquad (3.5)$$

If a_x is positive, the acceleration is in the positive x direction, we say that the particle is accelerating and its velocity will be increasing.

if a_x is negative, the acceleration is in the negative x direction, the negative acceleration does not necessarily mean that an object is slowing down (deceleration). If the acceleration is negative and the velocity is negative, the object is speeding up.

Example: 3.3

An object moving in a straight line according to the following relationship:

$$x(t) = 2t^3 - 3t^2 + 2t$$

Calculate the instant acceleration at t = 3 s.

Exercises

1. A bullet hit a 20 cm thick wooden board with a velocity of 500 $\frac{m}{s}$, passing the board and existing at a velocity of 360.6 $\frac{m}{s}$. Calculate the acceleration of the bullet at the moment of it exits the board.

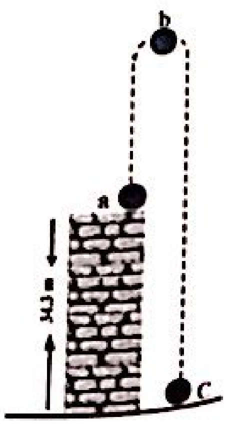
2. A car moved at seven in the morning from Bisha towards Makkah al-Mukarramah, the distance between them equal 450 km, and arrived in Makkah al-Mukarramah at four in the evening. Calculate the average velocity of the vehicle and time it took to travel this distance.

3. A train is moving in a straight line with a velocity of 30 $\frac{m}{s}$, and then slowed down until it stops after at time of 44 s, calculate the following:
   a. The train accelerated.
   b. The distance covered during this period until completely stopped.

4. A plane landed on the runway of an airport at an acceleration of 8 $\frac{m}{s^2}$, and stopped at the end of the runway after a time of 25 s, calculate the following:
   a. The velocity of the plane when it touches the ground.
   b. The length of the runway on which the plane landed.

5. Launch an up arrow and reach a height of 122.5 m, calculate the following:
   a. Total flight time.
   b. The speed at which the arrow reached the surface of the earth.

6. Throwing a stone vertically upwards from the top of a 34.3 m mosque minaret with a speed of 29.4 $\frac{m}{s}$, as shown in the figure. Calculate the following:
   a. The time required for the stone to reach its maximum height.
   b. The time needed for the stone to return to the Earth's surface.



c. $v_f = 0\ \frac{m}{s}$

$$v_f^2 = v_i^2 + 2g(y_f - y_i)$$

$$y_{max} = -\frac{v_i^2}{2\,g}$$

$$= \frac{(60)^2}{2 \times 9.8} = 183.7\ m$$

d. $v_f = v_i + g\ t$

$$t_{max} = -\frac{v_i}{g}$$

$$t_{max} = \frac{60}{9.8} = 6.11s$$

Flight time: The time required for the object to return to its original position, equal to the sum of the time of the rise and fall.

$$t_{total} = 2 \times t_{max} = 2 \times 6.11 = 12.22\ s$$

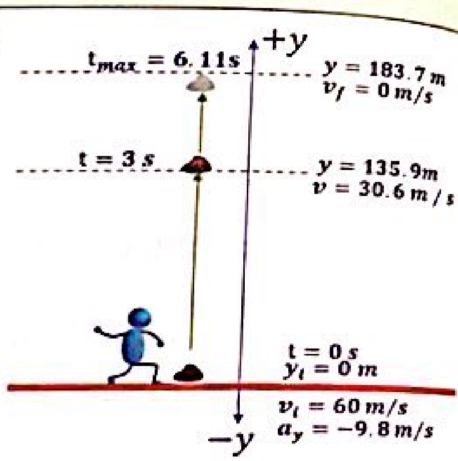
c. The velocity of the object when it reaches the earth is calculated from:

$v_i = 60\, m/s$. $t = 5s$

$$v_f = v_i + g\,t$$
$$= 60 + 9.8 \times 5 = 109\ \frac{m}{s}$$

Example: 3.6

Throw an object up from the surface of a 210 m high building at 60 $\frac{m}{s}$, calculate the following:



a. The velocity of the object after at time of 3 s.

b. The distance in which the body travels to the surface of the Earth after a time of 3s.

c. The maximum height that object can reach it.

d. The time needed for the object to reach its maximum height.

e. Flight time.

Solution

$$v_i = 60\ \frac{m}{s},\quad g = 9.8\frac{m}{s^2},\quad y_i = 0\ m$$

a. $t = 3s,$

$$v_f = v_i + g\,t$$
$$= 60 - 9.8 \times 3 = 30.6\ \frac{m}{s}$$

b. $t = 3s,$

$$y_f = y_i + v_i t + \frac{1}{2} g\, t^2$$
$$= 60 \times 3 - \frac{1}{2} \times 9.8 \times (3)^2 = 135.9\ m$$

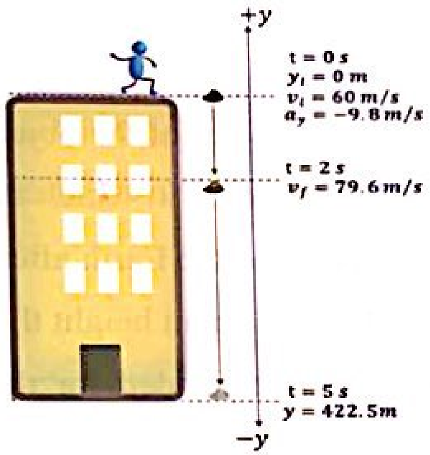
with a constant acceleration equal to the gravitational acceleration g. This acceleration does not depend on body properties, such as mass, density, or shape. Its value near the surface of the earth is equal to $g = 9.8\ m/s^2$ and its direction is always toward the center of the earth. To study the motion of objects under the influence of gravity, equations of motion can be used with constant acceleration, taking into account the replacement of the horizontal axis x with the vertical axis y.

Example: 3.5

Object was thrown down by $v_i = 60\ \frac{m}{s}$.

Calculate the following:

a. The velocity of the object after 2 s of its thrown.
b. The height from which the object was thrown, knowing that it reached the ground 5 s after it was thrown.
c. The velocity of the object when it reaches the surface of the earth.



Solution

a. Falling an object down at an initial velocity $v_i = 60\frac{m}{s}$. To calculate the velocity of the object 2 s after it is thrown:

$$v_f = v_i + g\ t$$

$$= 60 + 9.8\ \times 2 = 79.6\frac{m}{s}$$

b. To calculate the height from which the object was thrown, we use the equation:

$$y_f = y_i + v_i t + \frac{1}{2} g\ t^2$$

$$= 0 + 60 \times 5 + \frac{1}{2} \times 9.8 \times (5)^2 = 422.5\ m$$

1. Force

Through our daily practices, we know that an object can be moved through the muscular activity that the human body can performs, such as applying force on a ball when kicked in the foot or thrown in the hand. We also know that the Earth affects objects with a force called gravity. This force pulls objects toward the center of the Earth, and a force must be projected to raise any object to the top.

From the examples we have seen, forces can be divided into two types:

a. The forces of contact that have physical contact between objects, such as kicking or throwing a ball, pushing a cart, and stretching your spring.

b. Field forces and there is no physical contact between objects, such as the force of gravity, which is the force of attraction between the Earth and any other body that has mass. The force of gravity plays an important role in our daily life as it keeps objects on Earth and the moon in orbit around the Earth and planets around the sun.

From our experience, we know that force is a vector. Where the direction of the force with which a person is placed on a box placed on the ground is determined if the person pushes the object away from it or pulls it toward it. A group of forces can affect an object simultaneously. These forces can be in the same direction or in different directions.

To understand the nature of the force vector, we will study the deformation that occurs when you force it spring. Suppose a

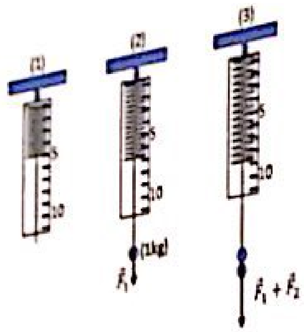


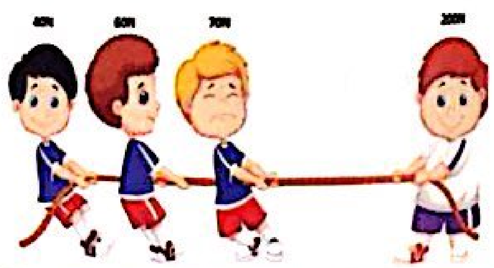
Figure 4.1: The effect of force on the spring

spring holds an indicator indicating the amount of elongation that will be a measure of how much force the spring affects the body. Figure (4.1) shows the original length of the original spring ($\ell_0 = 5\ cm$). And when the mass ($m_1 = 1\ kg$) is suspended, the spring is elongated under the influence of the weight strength $\vec{F}_1$ going down by $2cm$.

If we repeat the experiment and attach the spring two blocks $m_1 = 1\ kg$ and $m_2 = 1\ kg$, the spring will extend twice the first elongation, i.e 4 cm, under the effect of the forces $\vec{F}_1$ and $\vec{F}_2$. The resulting force $\vec{F}$ that perform the same elongation is the total of the forces $\vec{F}_1 + \vec{F}_2$. Since force is a vector quantity, we must use the rules of vector addition that we studied in the second chapter to obtain the resultant force affecting an object.

Example: 4.1

Find the direction and amount of the resultant forces as shown in figure.

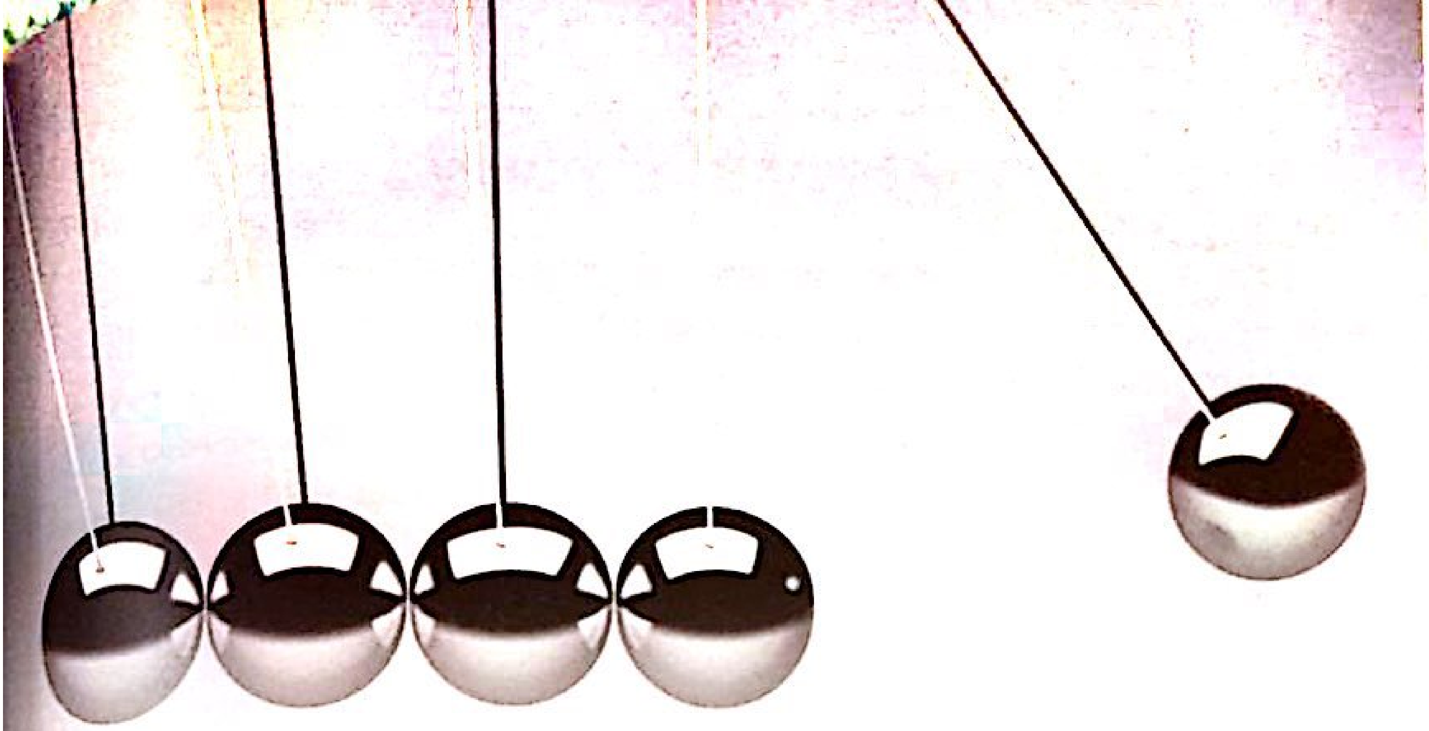


Solution

To find the force vector, assume the direction of the positive horizontal axis to the right..

$$\Sigma\vec{F} = 200\,\hat{\imath} - 70\,\hat{\imath} - 60\,\hat{\imath} - 40\,\hat{\imath} = 30\,\hat{\imath}$$

So, the resultant of the powers is 30 N with direction to the right.



Chapter 4:

laws of Motion

1. Force
2. Newton›s first law of Motion
3. Newton›s second law of Motion
4. Newton›s third law of Motion

In previous chapters we were studied the motion of objects while ignoring the causes of motion. In this chapter we will study how to generate an acceleration as a result of a force effect, and we will discuss Newton›s three laws of motion. These laws were first published before than three centuries by the focusing on a scientist Isaac Newton, in a summary entitled «Basic Principles of Natural Philosophy», in which Newton presented the concepts of mass and power and their relationship to acceleration. In this section we study the concept of mass and force and Newton›s three laws.

c. The speed of impact of the stone on the ground at point C.

7. A car moves in a straight line so that its position changes at every moment according to the following relationship:

$$x(t) = 3t - 4t^2 + t^3$$

Note that t is in seconds and x is in meters. Calculate the following:

a. A car position at $t = 1s,\ 2s,\ 3s,\ 4\,s$

b. The displacement of the car between the moments t = 2s and t = 4s.

c. The average velocity of the car between moments t = 2s and t = 4s.

d. The instantaneous velocity of the car at t = 3s.

8. A passenger bus runs on a straight line at a velocity of 45 $\frac{km}{h}$, and at one point the driver saw another car in front of him, which led to pressure on the brakes to stop the bus, but he collision with it after a time of 4 s from the beginning of his use of the brakes. If the car is 40 m from the front of the bus. Calculate the following:

a. The deceleration of the bus accelerated before the collision.

b. Bus speed at the moment of collision.

9. A plane accelerates from static until it reaches the required take-off speed of 360 $\frac{km}{h}$. Calculate the necessary acceleration for this, if the runway length is 1200 m.

10. Clarify the type of acceleration, positive (increase) or negative (deceleration) in each of the following cases.

a. Depress the accelerator pedal in the car.

b. An object falls from the top of a mountain towards the ground.

c. The moved a ball on the floor of a room and then stopped.

d. A plane is moving on the airport floor in preparation for take off.

e. The 100-meter race runner is starting run.

f. A motorcycle heading towards a red-light signal.

a mass of m located on a horizontal surface level with frictionless, it will move at an acceleration $\vec{a}$.

If we apply a force two times smaller than the first force on the same object, it will move at an acceleration equal to half of the first acceleration, but if we apply a force two times bigger on this body it will move at an acceleration equal to twice the first acceleration as shown in Figure 4.2.

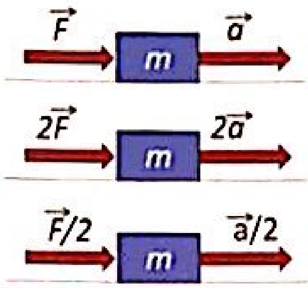


Figure 4.2: The force is proportional to the acceleration when the mass is fixed.

If we repeat the experiment and apply a force twice as large as $2\vec{F}$ on a mass twice as large as $2\,m$ then the object will move with the same $\vec{a}$. To obtain the same acceleration, the magnitude of force acting must increase with the same magnitude of increase in mass as shown in Figure 4.3. These observations from practical experiments are summarized in Newton's second law.

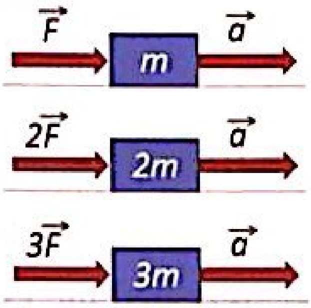


Figure 4.3: The force is proportional to the mass when the acceleration is fixed.

Newton's second law: When viewed from an inertial reference frame, the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

$$\sum\vec{F} = m\vec{a} \qquad (4.2)$$

Where $\sum\vec{F}$ represents the sum of the forces acting on the body, it is a vector of all forces affecting the body, m is the mass of the body, and $\vec{a}$ represents the acceleration.

From the definition of Newton's second law the unit of force can be defined in the international system of units (SI), which is Newton and symbolized by N, as follows: When a force of

Newton is defined as the force affects a body of mass 1kg, it results in acceleration of 1 $\frac{m}{s^2}$.

$$1N = \frac{kg \cdot m}{s^2}$$

Quiz

Choose the correct answers:

1. an object move at a constant velocity:

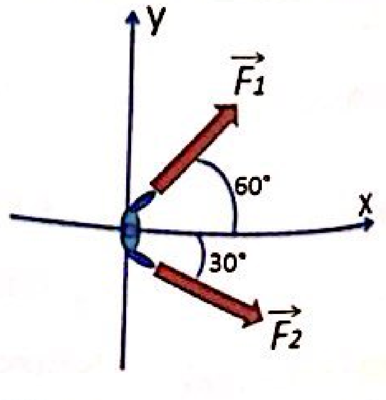
   a. There is only one force that affects this body.
   b. The sum of the forces acting on the body is not equal zero.
   c. The sum of the forces acting on the body is equal zero.

2. If we push an object whose mass is m onto a frictionless surface under the influence of the force of F, the result is that the acceleration is a. If we repeated the experiment and maintained the same force, but pushed a 3 m block. What is the value of acceleration?

   a. The same acceleration
   b. a/3
   c. 3a

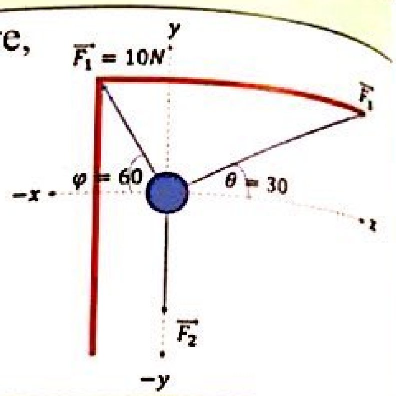
Example: 4.3

A 30 kg kid slides on a frictionless icy surface. The father and mother pull the child with two forces, as in the corresponding figure. The value of the first force is 9N and the second force is 12N. Calculate both the magnitude and direction of acceleration in which the child is moving .



Example: 4.2

Static body subjected to three forces as shown in figure, find the magnitude of $\vec{F_3}$, $\vec{F_2}$



Solution

As long as the object is static, the resultant force acting on it is equal to zero in both the vertical and horizontal components.

$$\sum \vec{F_x} = F_3 cos\theta - F_1 cos\varphi = 0$$

$$F_3 = \frac{F_1 cos\varphi}{cos\theta} = \frac{10\ cos60}{cos30} = 5.8\ N$$

$$\sum \vec{F_y} = F_1 sin\varphi + F_3 sin\theta - F_2 = 0$$

$$F_2 = F_1 sin\varphi + F_3 sin\theta$$

$$= 10 sin60 + 5.8 sin30 = 11.6\ N$$

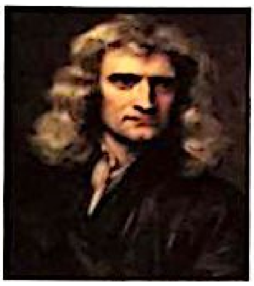
3. Newton's Second Law of Motion

Newton's first law explains how the resultant forces acting on the body are equal to zero for equilibrium, as this object remains static or dynamic in a straight line at a constant velocity. Newton's first law cannot describe the state of the body when un-equilibrium force or group of forces affects it .

We know from experience that changing the magnitude or direction of motion of a heavy object is more difficult than a light object. If we apply a horizontal force $\vec{F}$ to an object with

2. Newton's First Law of Motion

Newton's first law states that: in the absence of external forces and when viewed from an inertial reference frame, an object at rest remains at rest and an object in motion continues in motion with a constant velocity.



Isaac Newton lived in the period 1642-1727

$$\sum\vec{F} = 0 \qquad (4.1)$$

Where $\sum\vec{F}$ is resultant force acting on the object.

Newton's law confirms the principle of inertia of the object, as the object cannot change its state of static or motion at a constant velocity unless it is affected by an external force.

It is important to note that the concept of inertia is used to define mass. Suppose we bush two wooden boxes, for the first block m and the second block $2m$. The second box needs more effort to move it. If the mass of the body increase, its resist to change in its state of movement or rest is increase. The mass can then be defined as a property of the object that determines the amount of its resistance to change its state, i.e. the amount of its inertia.

The unit of mass in the international system of units (SI) is the kilogram and its symbol is kg. The mass m and weight F_w should not be confused as they are two different physical quantities. The weight of an object depends on how much the force of gravity affects it, as will be seen from Newton's second law. For example, a person with a mass of 100 kg would weigh 980 N on Earth, 162 N on the Moon, and 371 N on Mars.

In all cases, the forces of action and reaction that affect different objects are of the same type. For example, as shown in Figure (4.4), the sun affects the force of gravity $\vec{F}_{12}$ on the Earth, and the Earth affects the force $\vec{F}_{21}$ on the sun equal in magnitude to the force $\vec{F}_{12}$and its opposite direction.

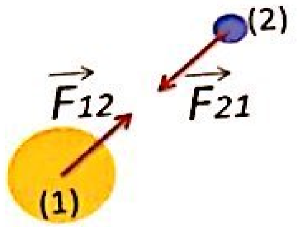


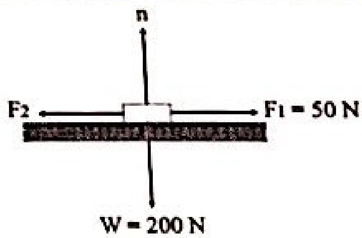
Figure 4.4: The force of action and reaction between the sun and the earth.

As a second example, let us assume that a young man in a state of static stands on the roof of a house, as shown in Figure (4.5). The Earth's gravitational force $\vec{F}_{12} = m\vec{g}$ pulls the young man downward, but he does not accelerate because he is fixed on the roof of the building. The building exerts on the young man the reaction force $\vec{F}_{21}$, this force prevents the young man from falling. Since the young man is constant, his acceleration is equal to zero, and by applying the second Newton's law to the young man, we find that: $\sum\vec{F} = \vec{F}_{21} + m\vec{g} = \vec{0}$ i.e. $F_{21}\hat{\jmath} - mg\hat{\jmath} = \vec{0}$ and thus the reaction force is $F_{21} = mg$.

Figure 4.5: The force of action and reaction of a young man standing on the roof of his house.

Example: 4.5

A static object lying on a table as shown in the figure, how much reaction force $\vec{n}$ is the object exposed to?



Solution

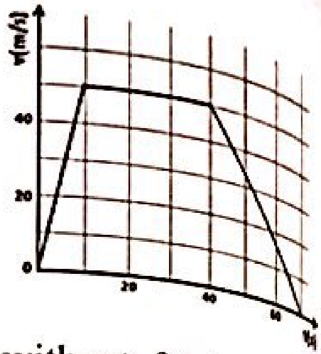
$\vec{F}_{12} = -\vec{F}_{21}$

n = W = 200

reaction force $\vec{n}$ exposed on the object is 200 N

Exercises

1. The figure represents the velocity diagram of the motion of an object in a straight line. What is the magnitude and direction of the force exerted on the body?



2. A block of ice with a mass of $m = 10g$ slides without friction, on an inclined surface at an angle of $\theta = 20°$.

   a. Find the magnitude and direction of acceleration of the ice cube.

   b. If the cube leave the top of the inclined surface with an initial velocity equal to zero, what is the time taken for the cube to reach the end of the slope and what is its velocity at this point, knowing that the length of the slope $d = 50cm$.

3. 10 kg block body hanging with two strings making angles of 60° and 30° as shown. Find the tension in string T_1 and T_2.

4. Find the acceleration and tension force of the two objects, as shown in the figure. The pulley is frictionless.

5. A person weighs himself in an elevator as shown in the figure. Find the value of its weight, if this person has a mass of 80 kg and the acceleration $a_y = \pm 3m/s^2$.

Solution

The component of forces affecting the child in the x direction:

$$\Sigma F_x = F_{1x} + F_{2x}$$
$$= 9\cos(60) + 12\cos(30°) = 14.89\text{N}$$

The component of forces affecting the child in the y direction:

$$\Sigma F_y = F_{1y} + F_{2y}$$
$$= 9\sin(60) - 12\sin(30°) = 1.8\text{N}$$

By applying Newton's second law to find acceleration components on the x and y axis:

$$a_x = \frac{\sum F_x}{m} = \frac{14.89}{30} = 0.5m/s^2$$

$$a_y = \frac{\sum F_y}{m} = \frac{1.8}{30} = 0.1m/s^2$$

Direction of acceleration components on x axis:

$$\theta = tan^{-1}\left(\frac{a_y}{a_x}\right)$$
$$= tan^{-1}\left(\frac{0.1}{0.5}\right) = 11.3°$$

It is magnitude:

$$a = \sqrt{a_x^2 + a_y^2}$$
$$= \sqrt{0.5^2 + 0.1^2} = 0.5m/s^2$$

Example: 4.4

What is the mass of a body weight on the surface of the Earth 24.4 N?

Solution

$F_w = ma$

$$m = \frac{F_w}{a}$$

$$= \frac{24.4}{9.8} = 2.5\ kg$$

4. Newton's Third Law of Motion

If you push the wall, you will find that the wall is pushing you back, and if you kick a ball with a certain force, you feel in return that the ball is affecting your foot strongly in the opposite direction, and as another example if you put a book on the table it will push it down while the table pushes it upward. By studying many of the situations that we meeting daily, Newton came to the conclusion of his third law, if an object affects the force of $\vec{F}_{12}$ on another body, then the second body affects with a force $\vec{F}_{21}$ on the first body equal to the force $\vec{F}_{12}$ in the magnitude and opposite to it in the direction:

$$\vec{F}_{12} = -\vec{F}_{21} \qquad (4.3)$$

One of these two forces is called the force of action and the other is called the force of reaction.

Newton's third law: If two objects interact, the force $\vec{F}_{12}$ exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force $\vec{F}_{21}$ exerted by object 2 on object 1: (Every action has an equal and opposite reaction.)

1. Work

We use the word work in our daily life and work has a very specific connotation in physics. We say that we did work if we influenced a constant force on a body and caused it to move in a certain direction. If this force did not cause a displacement of the body, then in this case we would not do work on the body. There are many different forms of work in nature, such as mechanical work, electrical work, thermal work, and others.

Work Done by a Constant Force

We will study the effect of force on a body in the three cases as shown in Figure (5.1). If we want to know how the force effect on motion of the body, consideration must be given not only to the magnitude of force but also its direction. Assuming that the magnitude of the force is constant in the three cases. We find that the horizontal force component influence on the car in the state (b) is greater than the state (a). On the contrary, we find that the force in the state (c) does not cause any movement of the body since the force is perpendicular to the direction of motion.

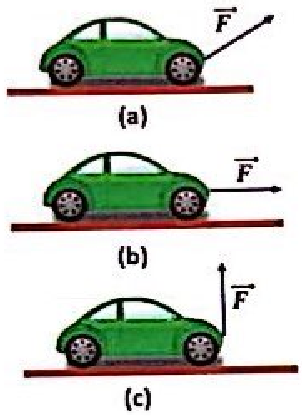


Figure 5.1: The effect of force direction on work

It is clear from the above that to study the effect of force on the body, it is necessary to take into account the vector direction of the force $\vec{F}$ and the displacement caused by this force $\Delta\vec{r}$. Suppose we have a force of $\vec{F}$ that affects an object and causes it to displace $\Delta\vec{r}$ and the angle between the direction of the force $\vec{F}$ and the displacement $\Delta\vec{r}$ is θ as in Figure (5.2), so the work done by this force can be defined as follows:

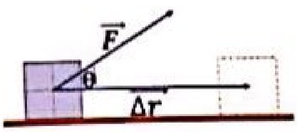


Figure 5.2: Work done by force $\vec{F}$.

The work W done on a system by an agent exerting a constant force on the system is the product of the magnitude $\vec{F}$ of the force, the magnitude $\Delta\vec{r}$ of the displacement of the point of application of the force, and $\cos\theta$, where θ is the angle between the force and displacement vectors:

$$W = \vec{F} \cdot \Delta\vec{r} = \Delta r\, F \cos\theta \qquad (5.1)$$

As is shown from equation (5.1), the work is a scalar quantity resulting from multiplying two vectors. When the force vector is perpendicular to the displacement vector, that is, $\theta = 90°$, the magnitude of work is equal to zero, as $\cos 90 = 0$. The sign of the work also depends on the direction of $\vec{F}$ relative to $\Delta\vec{r}$. The work done by the applied force on a system is positive when the projection of $\vec{F}$ onto $\Delta\vec{r}$ is in the same direction as the displacement. When the projection of $\vec{F}$ onto $\Delta\vec{r}$ is in the direction opposite the displacement, W is negative. Work in the international system is measured in units of Joule and is equal to Newtons. meter.

1 erg = 1×10^{-7} J
1eV = 1.602×10^{-19} J

Sometimes we use other units like erg and electron volts (eV).

$$J = N \cdot m = \frac{kg.m^2}{s^2}$$

Joule is defined as the work done by a force of one Newton when influencing a displacement of one meter on the direction of the force.

Rather, we find that the work is a transfer of energy to and from the system, that is, when the work done on the system is

Chapter 5:

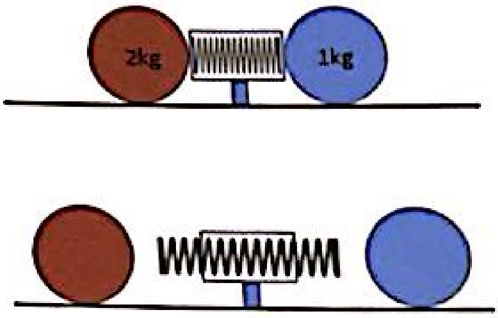
Work and Energy

1. Work
2. Kinetic Energy
3. Potential Energy
4. Work and Energy theory
5. Power

Energy is present in the Universe in various forms. Every physical process that occurs in the Universe involves energy and energy transfers or transformations. Unfortunately, despite its extreme importance, energy cannot be easily defined. The variables in previous chapters were relatively concrete; we have everyday experience with velocities and forces, for example.Although we have experiences with energy, such as running out of gasoline or losing our electrical Service following a violent storm, the notion of energy is more abstract.In this section, we will learn about the concept of work, kinetic energy,potential energy and power.

6. A man pushes a 100 kg box with a force that creates a 20 ° angle with the horizontal plane
   a. How much force is needed to move the box?
   b. If a man continues to push the box with the same force, what is its acceleration.

7. Suppose a spring is pressed into a cylinder and connected to two rollers, of the same size and having two different masses, on a smooth frictionless table top. A cylinder have been opened from both sides at the same time, and the spring pushes the balls in opposite directions. Which of the two balls will move away more quickly?



8. Car with mass of 1200 kg, start to go on straight path from static to reach a velocity of 100 $\frac{km}{h}$ during the 10 s. What is the necessary force for that?

9. A person pushes a box of 50 kg on a frictionless surface at an angle of 30° and a length of 50 m with an acceleration of 0.05 $\frac{m}{s^2}$. How much the magnitude of force needed to move the box with this acceleration?

10. Choose the correct answer: A chair is placed on a rug. Then a book is placed on the chair. The floor exerts a normal force
    c. on all three.
    d. only on the book.
    e. only on the rug.
    f. upwards on the rug and downwards on the chair.
    g. only on the objects you have defined to be part of the system.

Solution

The horizontal component of the force is the one that causes the work done, because the motion is in the horizontal direction only.

$$W = \vec{F} \cdot \overrightarrow{\Delta r}$$
$$= (5\hat{\imath} + 4\hat{\jmath}) \times 4\hat{\imath} = 20 \text{ J}$$

As the work is equal to the change in the kinetic energy:

$$W = KE_f - KE_i$$
$$= 20 - 5 = 15 \text{ J}$$

Example: 5.6

A car of mass of 1200 kg moves at an initial velocity of 20 $\frac{m}{s}$. Find the required work done by car's brakes for stopping completely within a distance of 30 m.

Solution

Since the car has stopped completely, its final kinetic energy is zero, and the work done by the car's brakes equals the change in its kinetic energy:

$$W = \frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2$$
$$= 0 - \frac{1}{2} \times 1200 \times 20^2 = -240000 \text{ J}$$

3. Potential Energy

There are some objects can produce a work because of their kinetic energy, but there are other objects that can show work due to the change of it is position and this energy is called the potential energy PE. If a man raises a body with a mass of m

By substituting the magnitude of force $F = m\,a_x$, where m is the mass of the cart, a_x is the magnitude of acceleration with which the cart moves:

$$W = m\,a_x\,x$$

From the laws of motion with a constant acceleration $v_f^2 = v_i^2 + 2a_x\,x$ here v_i is the initial velocity of the cart, v_f is the final velocity, we find that:

$$a_x x = \frac{1}{2}\,v_f^2 - \frac{1}{2}\,v_i^2$$

By substituting the value of $a_x x$ into the work equation, we get:

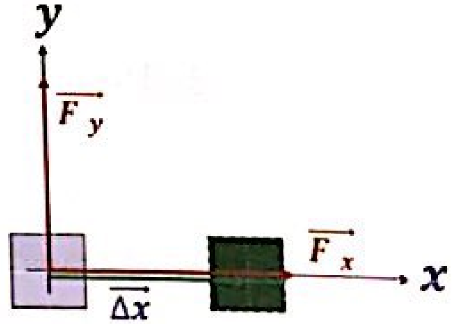
$$W = \frac{1}{2}\,m\,v_f^2 - \frac{1}{2}\,mv_i^2$$
$$= KE_f - KE_i = \Delta KE$$

That is, the work done W on the cart by horse has appear in the form of kinetic energy equal to ΔKE. Calculate the amount of KE of a moving object at velocity v at any point in time from the equation:

$$KE = \frac{1}{2}\,mv^2 \qquad (5.2)$$

Example: 5.5

A force $\overrightarrow{F} = 5\hat{\imath} + 4\hat{\jmath}\ N$ affected an object of mass $5\,kg$ and moved it in a horizontal displacement of 4 m Find:



a. The work done on the body by this force.

b. If the body's initial kinetic energy is equal to 5 J, find it is final kinetic energy.

Example: 5.3

A force of 200 N affected the direction of making a 60° angle with the horizontal to push the stroller. Calculate the work done to move the cart 10 m in the direction of force.

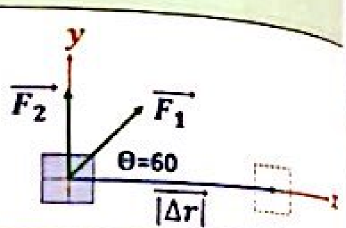
Solution

$$W = \Delta r\, F \cos\theta$$

$$= 200 \times 10 \times \cos 60 = 1000\ \text{J}$$

Example: 5.4

Two forces of 200 N each affect an object as well as to move it 2 m in the positive direction of the x-axis. Find the total work done by the two forces.



Solution

Since the force F_2 is perpendicular to the direction of movement of the object, it does not perform a work and the work done only by the force F_1.

$$W = \Delta r\, F \cos\theta$$

$$= 200 \times 2 \times \cos 60 = 200\ \text{J}$$

2. Kinetic Energy

Figure 5.3: A horse pulling a cart to gain mobility.

Body is said to have a kinetic energy KE if it is able to produce a work, so everybody can move at a velocity v has an amount of KE. Suppose a horse pulls a cart in straight line, the work done by the horse on the cart to move it a displacement x, is equal to:

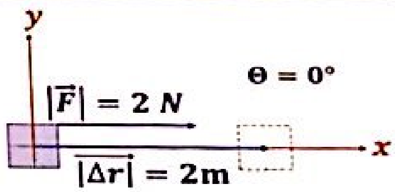
$$W = \vec{F}.\vec{x}$$

positive, the energy is transferred to it, and when the work is negative, the energy is transferred from the system.

Work is absent even in the presence of an applied force, as energy has not been transmitted to and from the system, such as the centrifugal force in the case of the rotational motion of a body, For example, the movement of the Earth's rotation in its orbit around the sun, it does not work because the kinetic energy of the body has not changed, and the direction of force is perpendicular to the direction of movement.

Example: 5.1

Calculate the work done by a horizontal force of 2 N and refer to the positive direction of the x-axis on an object whose displacement is 2 m in the positive direction of the x-axis.



Solution

$$W = \Delta r \, F \cos\theta$$

$$= 2 \times 2 \times \cos 0 = 4\,J$$

Example: 5.2

A man raises a bucket of 100 N at a constant velocity from a vertical well. If the work done to get the bucket out of the hole is 1000 J. Find the depth of the well.

Solution

$$W = \Delta r \, F \cos\theta$$

$$\Delta r = \frac{W}{F\cos\theta}$$

$$= \frac{1000}{100 \times \cos 60} = 10\,m$$

Example: 5.8

The force of $\vec{F} = 10\,\hat{\imath} + 20\,\hat{\jmath}\ N$ affected a static particle of 2 kg in the xy plane at position $r_1 = 2\,\hat{\imath} + 1\,\hat{\jmath}\ m$ and moved it to position $r_2 = 4\,\hat{\imath} + 3\,\hat{\jmath}\ m$

a. Find the work done on the particle by the force $\vec{F}$.

b. Find the potential energy.

c. Find the final velocity.

Solution

a. $\Delta\vec{r} = r_2 - r_1 = (4\,\hat{\imath} + 3\,\hat{\jmath}) - (2\,\hat{\imath} + 1\,\hat{\jmath}) = 2\,\hat{\imath} + 2\,\hat{\jmath}$

$$W = \vec{F}\cdot\Delta\vec{r}$$
$$= (10\,\hat{\imath} \times 20\,\hat{\jmath})\cdot(2\,\hat{\imath} + 2\,\hat{\jmath}) = 60$$

b. $\Delta PE = mg(y_2 - y_1)$

$$= 2 \times 9.8 \times (3-1) = 39.2\ \text{J}$$

c. $\Delta KE = \frac{1}{2}\, m\, v_f^2$, where $v_i = 0$

$$W = \Delta KE + \Delta PE$$

$$60 = \frac{1}{2} \times 2 \times v_f^2 + 39.2$$

$$v_f = 4.56\ \frac{m}{s}$$

Example: 5.9

A force that exert on a body of 6 kg in mass and that it moves in a horizontal distance given as a function of time in relation to: $x(t) = 5t^2 - 6t + 10$ where x in meters, t in seconds. Find the work done by force during the first five seconds if the body moves from static.

Solution

$x(t) = 3t^2 - 6t + 10$

$$v = \frac{dx}{dt} = 6t - 6$$

During five second $v = 24\ \frac{m}{s}$

Using work and energy theory, we find that:

$W = \Delta KE + \Delta PE$

Since the body is moving horizontally, then: $\Delta PE = 0$

$W = \Delta KE = \frac{1}{2}\, m\, v_f^2$, where $v_i = 0$

$$W = \frac{1}{2} \times 6 \times (24)^2 = 1728\ J$$

5. Power

Power is defined as the rate of work done, measured in units of watt

$$W = \frac{J}{s} = \frac{kg.m^2}{s^3}$$

$$P = \frac{dW}{dt} \qquad (5.5)$$

vertical to a higher distance $\Delta h = h_f - h_i$, where h_f is the top level and h_i is the lower level. the work done to raise the body is $W = mg\Delta h$, this work is stored in the body in potential energy form, as in Figure (5.4):

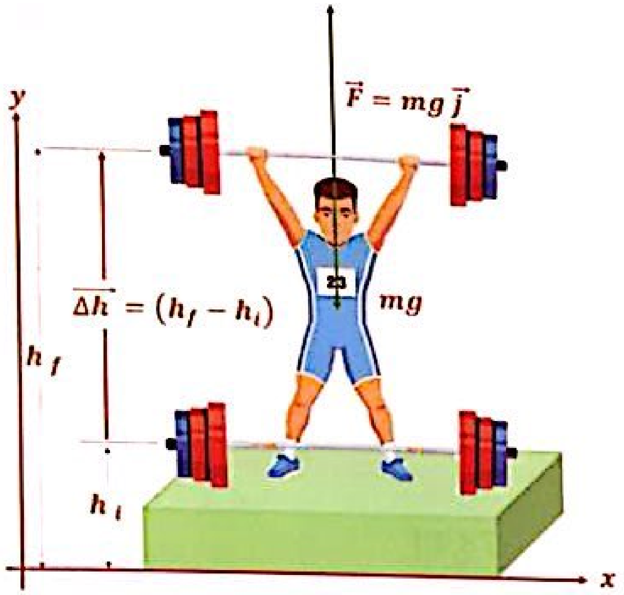


Figure 5.4: A player who raise a heavy ball and gain some potential energy relative to the surface of the field.

$$W = m\,g\,\Delta h = mg\left(h_f - h_i\right)$$
$$= mgh_f - mgh_i$$
$$= PE_f - PE_i = \Delta PE$$

$$\Delta PE = m\,g\,\Delta h \qquad (5.3)$$

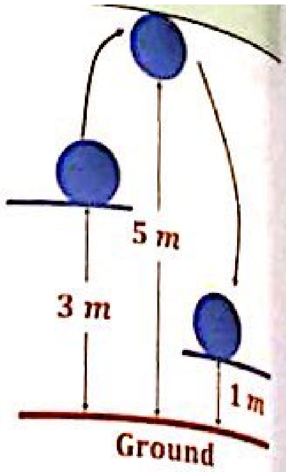
The absolute value of potential energy cannot be set because it depends on the vertical position of a reference point. The potential energy is also measured in joules, and is positive if the body is higher than the reference level, and negative if the body is below this level, but the change in the potential energy ΔPE is a fixed amount that does not depend on the reference level.

Example: 5.7

A particle of mass 2 kg at a height of 3 m from the Earth's surface.

a. If the body is raised to a height of 5 m, calculate the change in its potential energy.

b. If the particle falls to a height of 1 m, calculate the change in its potential energy.



Solution

$$\Delta PE = mg(h_f - h_i)$$
$$= (2 \times 9.8) \times (5 - 3) = 39.2 \text{ J}$$

$$\Delta PE = mg(h_f - h_i)$$
$$= (2 \times 9.8) \times (1 - 5) = -78.4 \text{ J}$$

4. Work and Energy theory

Figure 5.5: Photo of different energy.

"Energy is neither destroyed nor created from scratch" this term is called the law of conservation of energy, but energy is transferred from one form to another. The Energy conservation Law can be written extensively for work and energy theory:

The work done of any system is equal to the sum of the change in the kinetic and potential energy.

$$W = \Delta KE + \Delta PE \tag{5.4}$$

$$\vec{F} \cdot \Delta\vec{r} = \left(\frac{1}{2}\, m\, v_f^2 - \frac{1}{2}\, m v_i^2\right) + (\, mgh_f - mgh_i)$$

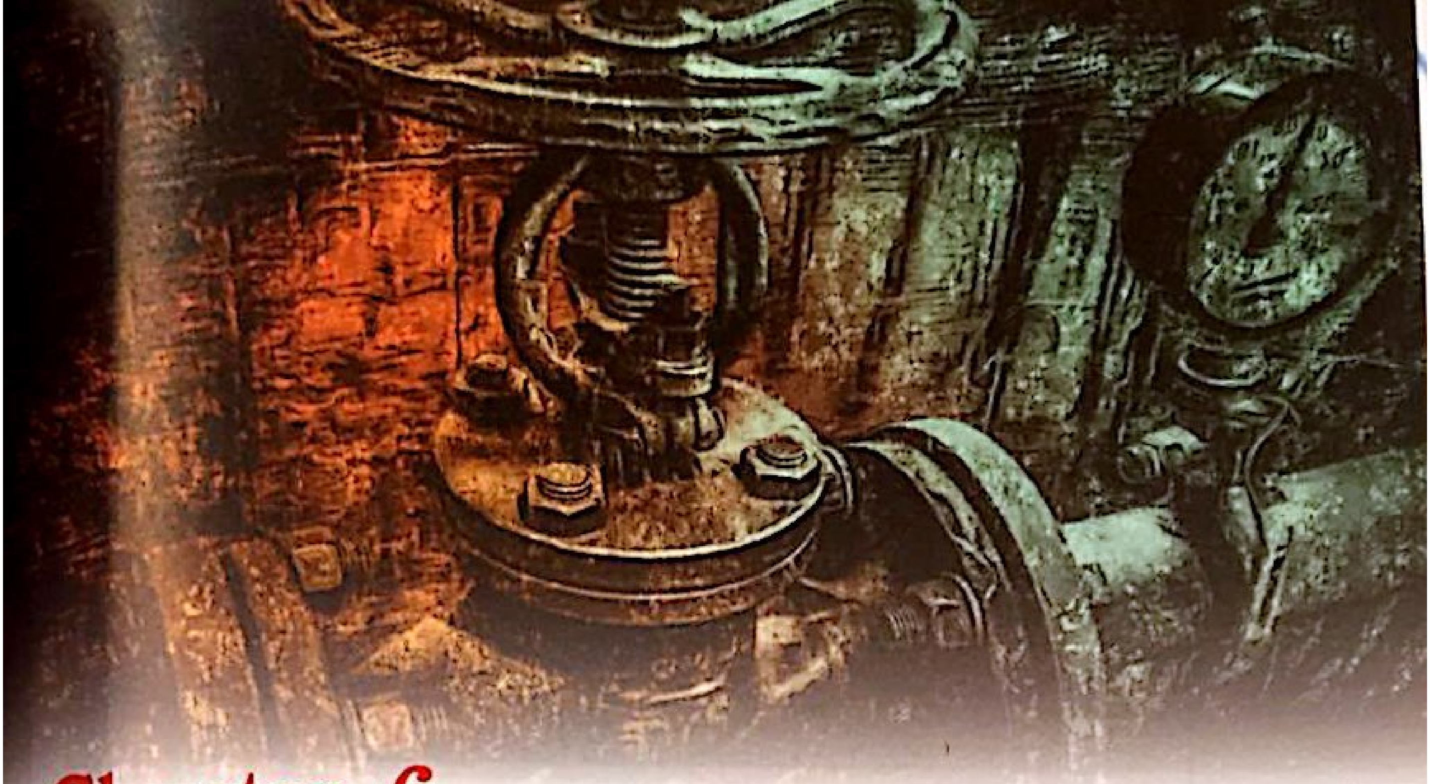
a. Find the work done on the body by force.

b. Find the final velocity of the particle.

10. 10 kg body moves as a function of time by relation:

$$x(t) = 12t^3 - 2t^2 - 12$$

Where x in meters, t in seconds, find the kinetic Energy during the first three seconds if the body moves from static.



Chapter 6 :

Elasticity and Fluid Mechanics

1. Elasticity
2. Density
3. Pressure
4. Fluid flow

In this chapter, we will study some of the properties of the material, whether in its solid state, such as the study of elasticity coefficients, or in its liquid and gaseous state, which we call fluids.

Exercises

1. A body subjected to force of 10 N and if it moves about 5 m, calculate the work done of the body if the force and distance are in the same direction.

2. Calculate the work required to raise a 2 kg block to a height of 2 m.

3. A force equal to $F = 15\hat{\imath} + 25\hat{\jmath}\ N$ affects an object that moves it from position $r_1 = (2,7)$ to position $r_2 = (5,9)$, determine the work done on the body by force.

4. If the displacement vector of the body $\vec{x} = \hat{\imath} + 2\hat{\jmath}\ m$ and the vector of the force acting on it $\vec{F} = 2\hat{\imath} + 5\hat{\jmath}\ N$, calculate the work that is applied to the body.

5. If the displacement vector of an object is $x = 15\ m$, and the force of the influence affecting it is $F = 12\ N$, and the angle between them is equal to $\theta = 30°$, find the work done on the body by that force.

6. A body with a mass of 50 kg move horizontally at an initial velocity v_i, then its velocity decreased to $1\ \frac{m}{s}$ under the affecting of an external force, and the work done on the body by this force was 3000 J, compute its initial velocity.

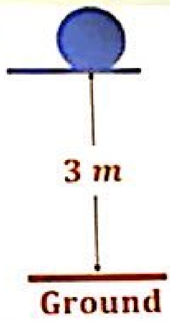
7. A man pulls a 30 kg particle to the top of the inclined surface at an angle of 30°, if the applied force is parallel to the surface, find out the work needed to pull the particle to the highest distance of 4 m.

8. An elevator of 500 kg climbed from the first floor at a height of 3 m to the fourth floor at a height of 12 m. Find the change in potential energy.

9. A particle with a mass of 10 kg is move with the initial velocity $v_i = 5\ \frac{m}{s}$ from the point $r_1 = (5,3)$ to the position $r_2 = (8,5)$, after subject to a force of $F = 120\,\hat{\imath} + 50\,\hat{\jmath}\ N$.

Example: 5.10

A particle of mass 2 kg was raised to the higher distance of 3 m from the Earth's surface at a time of power of 5 s.



a. Calculate the work done to raise the body.

b. Calculate the power to lift the particle.

Solution

$$W = F.x$$

$$= mg\,.x = 2 \times 9.8 \times 3 = 58.8\ \text{J}$$

$$P = \frac{W}{t}$$

$$= \frac{58.8}{5} = 11.76\ W$$

Example: 6.1

A force of 2500 N affected a metal wire 10 m long and 3.5 mm in diameter, extending by 0.5 cm find:

a. Stress.
b. Strain.
c. Young modulus

Solution

$$Stress = \frac{F}{A}$$

$$= \frac{2500}{\pi \times (1.75 \times 10^{-3})^2} = 2.6 \times 10^8 \frac{N}{m^2}$$

$$Strain = \frac{\Delta L}{L}$$

$$= \frac{0.5 \times 10^{-2}}{10} = 5 \times 10^{-4}$$

$$Y = \frac{Stress}{Strain}$$

$$= \frac{2.6 \times 10^8}{5 \times 10^{-4}} = 5.2 \times 10^{11} \frac{N}{m^2}$$

Bulk modulus: Elasticity of volume

When affecting a cube object with pressure (stress) from all sides as in Figure (6.3), this body will have a volume strain and decrease in size as a result of pressure from all directions so that:

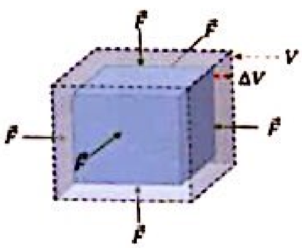


Figure 6.3: Pressure affected by a cube from all directions

$$\frac{F}{A} = -B\frac{\Delta V}{V} \qquad (6.2)$$

B is called a Bulk modulus, and the negative signal indicates a decrease in body size as a result of increased pressure on it.

Example: 6.2

A copper cube with a side length of $5 \times 10^{-2}\ cm$, if we affect on it with a vertical force of $1.5 \times 10^{3}\ N$, its volume reduced by $5 \times 10^{-6}\ cm^{3}$. Calculate the Bulk modulus for this cube?

Solution

$$\frac{F}{A} = B\frac{\Delta V}{V}$$

$$B = \frac{F\ V}{A\ \Delta V}$$

$$= \frac{1.5 \times 10^{3} \times 125 \times 10^{-6}}{25 \times 10^{-4} \times 5 \times 10^{-6}} = 1.5 \times 10^{7}\frac{N}{m^{2}}$$

Shear modulus: Elasticity of shape

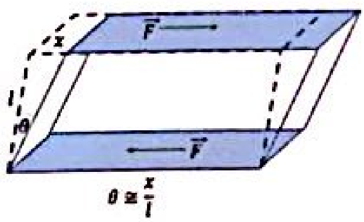


Figure 6.4: Shear strain affected an object

If an object is exposed to a tangential force on its surface as in Figure (6.4), it causes $\frac{F}{A}$ stress. A slippage in the body layers are causing a small shear strain in the body at an angle of $\theta \cong \frac{x}{L}$. This strain proportional with the affecting stress.

$$\frac{F}{A} = S\frac{x}{L} \tag{6.3}$$

S represents the shear modulus.

1. Elasticity

Elasticity coefficients measure the rigidity or elasticity of the material in terms of changing its length, size or shape as a result of affecting it with external force.

Young's modulus: Elasticity of length

If a solid material is exposed to the influence of an external force, a change occurs in its shape, depending on the amount and direction of the force. To simplify the idea, we begin with a metal wire has L length suspended from one end as in Figure (6.1). The vertical force $\vec{F}$ working down on this wire. By increasing the force affecting the wire, the elongation that occurs with the wire increases, where ΔL is the elongation in this wire.

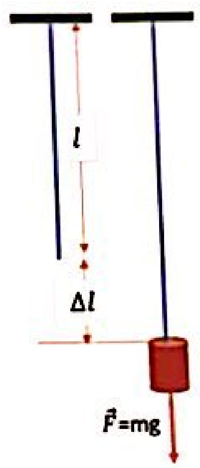


Figure 6.1: Tension of a metal wire affected by force $\vec{F}$.

$$F \propto \Delta L$$

$$F = k\,\Delta L$$

The constant of proportionality in the previous law is known as the hook constant, which depends on the nature of the material as well as the dimensions of the material. To obtain a characteristic constant of the material which does not depend on its dimensions we replace the force affecting the wire with stress, and replace the elongation of the incident of the wire with strain.

Stress: Defined as the force affecting the unit of areas from the wire $\frac{F}{A}$, measured by $\frac{N}{m^2}$ units.

Strain: It is known as the amount of expansion of the wire relative to its original length of $\frac{\Delta L}{L}$, which is unitless.

$$\frac{F}{A} = Y\frac{\Delta L}{L} \tag{6.1}$$

The Y is called the Young's modulus or longitudinal elasticity coefficient: it is known as the ratio between stress and strain.

The Young's modulus is a characteristic amount of the material and does not depend on its geometric dimensions, measured by $\frac{N}{m^2}$ units.

The material goes through several stages when influenced by longitudinal stress as shown in the Figure (6.2), on which three basic points appear.

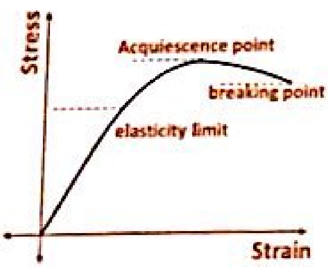


Figure 6.2: Curves the stress and strain of a wire.

The first point is the elasticity limit. This elasticity limit is the maximum stress that can be applied to the wire before it does not return to its original length, even if the stress is removed. The second point is the point of acquiescence: at this point a large elongation of the wire occurs when a small stress is exerted and the distortion of the wire remains. The last point is the breaking point at which the wire is cut from its weakest point.

Example: 6.5

Submarine at a depth of 30 m below sea level. Find the amount of force that seawater pressure affects on a cover at the top of the submarine with area 2 m^2. The density of seawater is 1025 kg/m^3.

Solution

$F = A\,P, \quad P = h\,\rho\,g + P_0$

$F = A\,(h\,\rho\,g + P_0)$

$= 2 \times [(30 \times 1025 \times 9.8) + 10^5] = 802700\ N$

From the Equation (6.6) it is clear that the pressure inside the liquid varies according to the depth of the liquid and is not affected by the shape of the container containing the liquid, and that any increase in pressure on the liquid will be transferred to all parts of the liquid, and this result is known as Pascal's law.

Pascal's Law: It states that if any part of a balanced liquid falls into a limited space under the influence of a pressure, the pressure is transferred to all parts of the liquid.

One of the applications of this law is hydraulic presses. A small piston is used whose area a affects a small force f of a liquid. So, the pressure of the liquid on the piston is $p = \frac{f}{a}$, as shown in Figure (6.7). At the other end of the tube is a large piston whose area A and the fluid affects it with a strong force F, the pressure on it is also $p = \frac{F}{A}$, and as a result of the transfer of the entire pressure from the small piston to the large piston we find that:

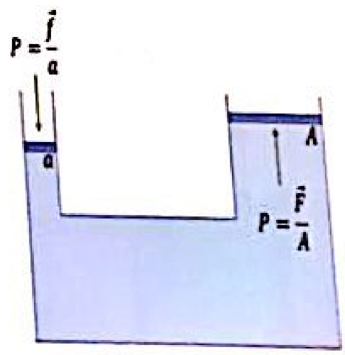


Figure 6.7: Transfer pressure to all parts of the container

$$P = \frac{f}{a} = \frac{F}{A}$$

That is, the strength at the other end is multiply by the ratio between the two areas of the ends of the tube.

Example: 6.6

In the hydraulic piston, the radius of the small and large piston is 2 cm, 20 cm respectively. A force of 2000 N is generated on the large piston. Calculate the force acting on the small piston.

Solution

$$\frac{f}{a} = \frac{F}{A}$$

$$f = F\,\frac{a}{A}$$

$$= \frac{2000 \times \pi\,(2 \times 10^{-2})^2}{\pi\,(20 \times 10^{-2})^2} = 20\ N$$

Pressure gauges

1. The Barometer

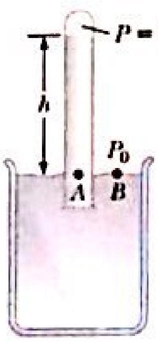


Figure 6.8: A mercury barometer

The mercury barometer is used to measure atmospheric pressure. It is composed of a long glass tube, which is filled with mercury and placed inverted, in a cup of mercury, so the column of mercury fell in the tube, and its top became 0.76 m above the surface of the mercury in the cup, as shown in Figure (6.8). So, the pressure of the mercury column at the point inside the tube is equal to the atmospheric pressure at the point at the same level outside the tube in the cup, thus calculating the atmospheric pressure from the relationship:

$$P_0 = \rho g h$$

Example: 6.3

Cube 10 cm long, affected by a tangential force of its upper surface of 10^6 N, causing a displacement of 0.03 cm for the upper side related to the lower side. Calculate the value of the shear modulus.

Solution

$$\frac{F}{A} = S\frac{x}{L}$$

$$S = \frac{F\,L}{A\,x}$$

$$= \frac{10^6 \times (10 \times 10^{-2})}{(10 \times 10^{-2})^2 \times (0.03 \times 10^{-2})} = 3.3 \times 10^{10}\,\frac{N}{m^2}$$

2. Density

Density ρ is defined as mass per unit volume, measured by the unit of $\frac{kg}{m^3}$.

$$\rho = \frac{m}{V} \tag{6.4}$$

Figure 6.5: A group of different liquids of density

m represents body mass and V represents body size. High-mass material is higher density than those with low mass of the same size, Figure (6.5) shows some of fluids, with the highest density fluids at the bottom of the cylinder and low-density fluids at the top of the cylinder. The density of any substance mostly decreases as the temperature increase.

Example: 6.4

Calculate the density of Glycerol if the size of 100 gm of it is equal to 79.3 cm^3.

Solution

$$\rho = \frac{m}{V}$$

$$= \frac{100 \times 10^{-3}}{79.3 \times 10^{-6}} = 1261 \frac{kg}{m^3}$$

3. Pressure

Pressure at point: defined as the perpendicular force that affects the unit of the spaces around that point, the pressure is measured by the Pascal unit $P_a = \frac{N}{m^2}$

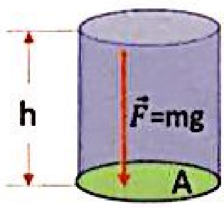


Figure 6.6: Colum liquid pressure onto the bottom of the container

$$P = \frac{F}{A} \tag{6.5}$$

To calculate the pressure generated by a column of liquid placed in a closed container its depth h and the area of its base A has been filled to the end by a liquid density ρ, as is in the Figure (6.6). The force at the bottom of the container is equal to the weight of the liquid above it and therefore:

$$F = m\,g$$

$$m = \rho\,V, \quad V = A\,h$$

$$F = \rho\,h\,A\,g,$$

$$P = \frac{F}{A} = \rho\,g\,h \tag{6.6}$$

$$\rho V_1 = \rho V_2$$

$$\rho\, A_1 v_1 dt = \rho\, A_2 v_2 dt$$

$$A_1 v_1 = A_2 v_2 \qquad (6.7)$$

This is the continuity equation, and from this equation we conclude that: the larger area of the tube section has the lower flow velocity. The amount $A\,v$ is also a constant, and is called the flow rate R.

Fluid flow rate $R = Av$: Defined as the size of the fluid that crosses the fluid stream section area in the unit of time, measured in a unit $\frac{m^3}{s}$.

Example: 6.9

The water flows by pressure $3 \times 10^5\ P_a$ into a horizontal tube with velocity $1\ \frac{m}{s}$. The radius of tube is narrows from 0.2 m to 0.1 m. Calculate the flow speed in the narrow part of the tube.

Solution

$$A_1\, v_1 = A_2\, v_2$$

$$v_2 = \frac{A_1}{A_2} v_1$$

$$= \frac{\pi\, r_1^2}{\pi\, r_2^2}\ v_1$$

$$= \frac{0.2^2}{0.1^2} \times 1 = 4\ m/s$$

Bernoulli's Equation

Now we study the movement of an ideal liquid inside a tube as represented in Figure (6.11), we assume that the area of the section and the height of the ground at a ، b is (A_1, h_1) ، (A_2, h_2), and that the speed and pressure of the liquid at them (v_1, P_1) ،(v_2, P_2), respectively. From the conservation of energy law, the total energy at the point a is equal to the total energy at the point b. Energy at any point such as a or b from three factors:

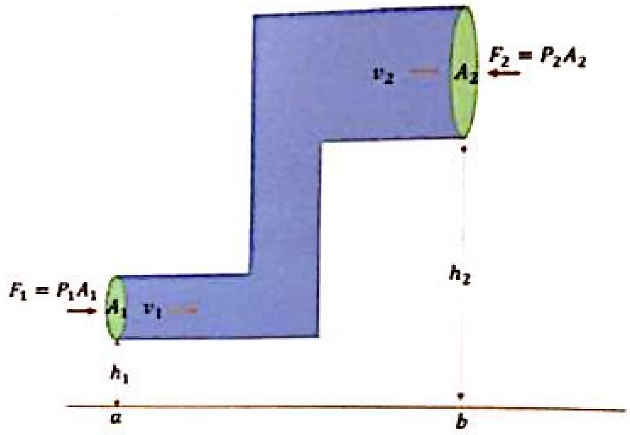


Figure 6.11: Fluid flow in an unequal section and height

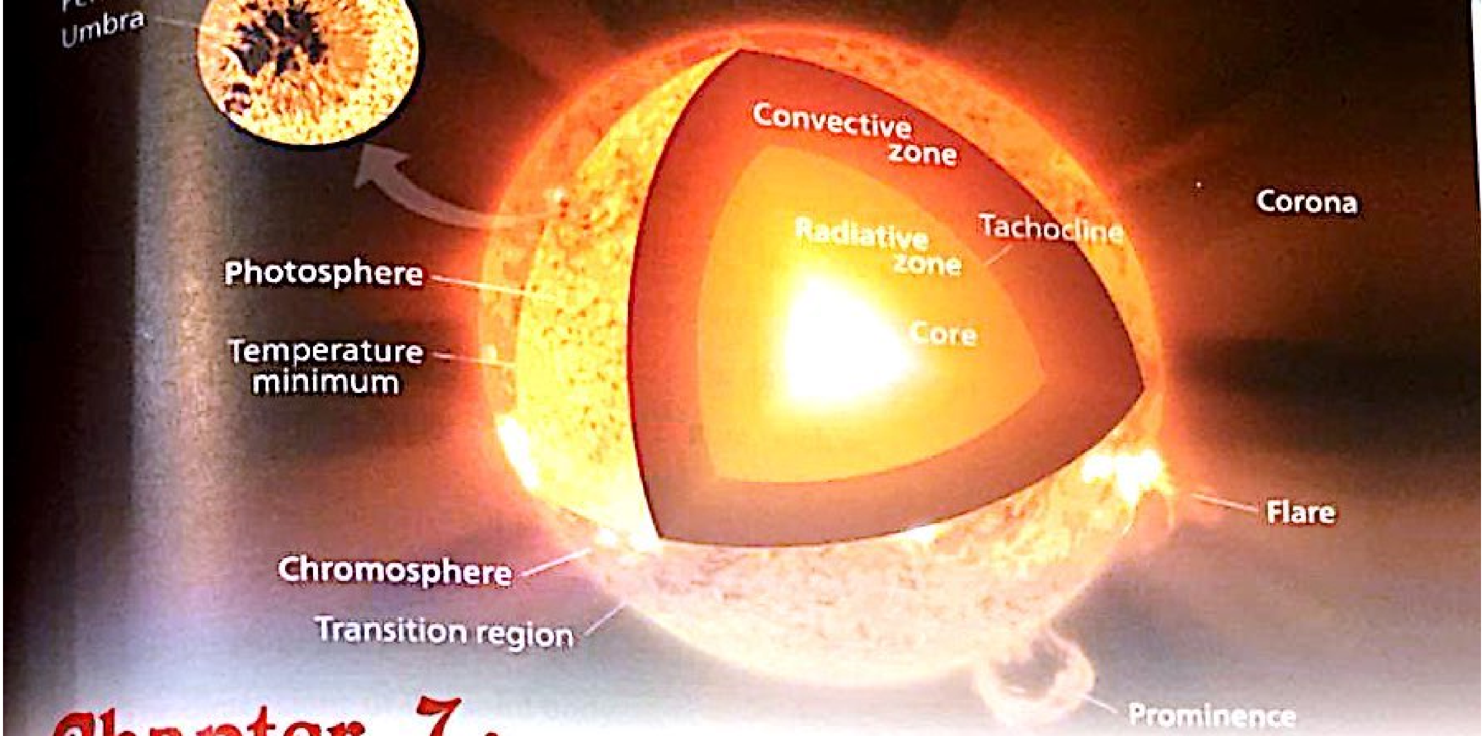
1- The potential energy obtained by the liquid because of its height h from the earth's surface and equal $m\,g\,h$, where m is the mass of the liquid that passes in the time dt.
2- The kinetic energy obtained by the liquid because of its speed v and equal to $\frac{1}{2}\,m\,v^2$.
3- Mechanical work exerted to push the liquid into the pipes and equal to the result of multiplying the force by the distance $P\,A\,v\,dt$

By applying the conservation of energy law:

$$m\,g\,h_1 + \frac{1}{2}\,m\,v_1^2 + P_1\,A_1\,v_1\,dt$$

$$= m\,g\,h_2 + \frac{1}{2}\,m\,v_2^2 + P_2\,A_2\,v_2\,dt$$

By compensating for the mass $m = \rho\,A\,v\,dt$ we get:



Chapter 7:

Heat

1. Temperature scales
2. Thermal expansion
3. Specific heat
4. Heat transfer

Heat is a type of energy, just like the potential energy and kinetic energy. In our daily life we are exposed to many natural phenomena that can be explained according to the laws of heat and thermodynamics. In this section, we will study some basic concepts about heat, we start by recognizing the temperature measurements, then we discuss the expansion of solids and liquids as a result of exposure to heat, and we address the concept of the quantity of heat and heat capacity, and we conclude our study in this section by identifying the different ways of heat transfer.

4. Fluid flow

Our study will be limited to the ideal fluid that flows into a stable layer, in which the fluid flow speed is low and the liquid slips into layers that slide on top of each other. Let's explain the characteristics of the ideal fluid in the following points:

1. Incompressible: its size does not change if it remains under constant temperature and pressure, and since its size is constant, its density does not change.
2. Non-Viscosity: Viscosity expresses the forces of friction between the fluid layers during flow, and the ideal fluid is characterized by a non-viscosity, i.e. no friction between its layers during flow.
3. Regular flow: the speed of fluid particles at a certain point is fixed over time, the velocity varies from point to point, and each part of the fluid is movement along a constant line that does not change the shape of the stream and is called the flow line.
4. Its non-circular flaw: the parts of the fluid have no torque around the point at which they pass.

Equation of Continuity

We assume that an ideal liquid has its density ρ in a variable-section tube as described in the Figure (6.10), and we assume that the fluid velocity at A_1 is v_1 and at A_2 is v_2. The amount of mass that enters through the section area A_1 in a time dt equal to the amount of mass that comes out of the section area A_2 in the same time period dt

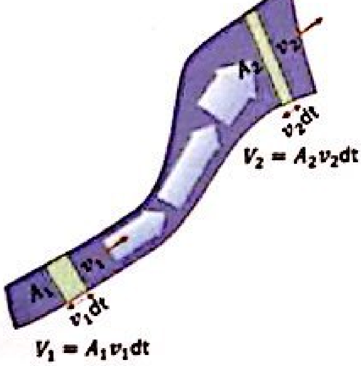


Figure 6.10: Fluid flow in an asymmetric tube

$$m_1 = m_2$$

9. Hydraulic piston small and large cylinders with diameters (60, 180) respectively. Calculate the force generated by the large piston if the force affecting the small piston is 10 N.

10. It turns out there is a hole in one side of the tank filled with water and it is open to space. The hole is located 16 m below the water level. If the water flow rate is 2.5×10^{-3} m^3/min calculate:

    a. The speed of the rush of water from the hole.
    b. The diameter of the hole.

11. Natural gas pipe diameter of 0.25 m gives 1.55 m^3 of gas per second. calculate the gas speed?

2. The Manometer

The manometer shape is in the form of a letter U, that contains a liquid and one of its ends is connected to the container to which the pressure is intended to be measured P, so the other end is open to the air as shown in Figure (6.9). The gas pressure in the container is calculated from:

$$P = P_0 + \rho g h$$

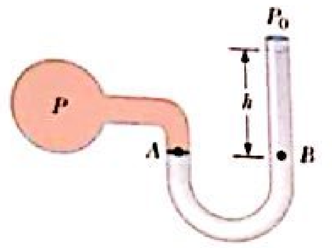


Figure 6.9: A mercurial manometer

Example: 6.7

How long is the tube that we need to make a water barometer?

Note: (Atmospheric pressure is $1 \times 10^5\ Pa$ - gravitational acceleration $g = 9.8\ \frac{m}{s^2}$ - water density $1000\ \frac{kg}{m3}$)

Solution

$$P_a = \rho\ g\ h$$

$$h = \frac{P_a}{\rho\ g}$$

$$= \frac{1 \times 10^5}{1000 \times 9.8} = 10.2\ m$$

Example: 6.8

The height of mercury in open branch of the manometer relative to the surface of mercury in container branch is 40 cm, the mercury density is $13600\ \frac{kg}{m^3}$, atmospheric pressure $1 \times 10^5 Pa$ and the gravitational acceleration g= $9.8\ \frac{m}{s^2}$. Calculate the pressure of the trapped gas in the container.

Solution

$$P = P_a + \rho\ g\ h$$

$$= 1 \times 10^5 + (13600 \times 9.8 \times 0.4) = 153312\ Pa$$

Exercises

1. A force of 1000 N affected a metal wire 100 m long and 0.003 m in diameter, extending by 0.5 m. Find the Young modulus of this metal.

2. Liquid in a 0.5 m^3 cylinder with a mass of 10 kg. Calculate the density of the liquid.

3. If you know that the water density is 1000 kg/m^3, the mercury density is 13600 kg/m^3 and the atmospheric pressure value 1.03×10^5 N/m^2 Calculate the amount of pressure on the bottom of the pot 40 cm deep when it is full:

    a. With water .

    b. With mercury.

4. Parallelogram dimensions (2, 3, 4) m and its mass 5000 kg calculate the largest and smallest pressure affects the parallelogram on the ground.

5. Student his mass 65 kg and the area below the surface of one of his feet is 250 cm. calculate the pressure on the ground in both cases:

    a. When he's standing still on one of his feet.

    b. When he stands still on both feet.

6. If the mass of a planet is 5.64×10^{16} kg and the radius of this planet is 6.0×10^7 m. Calculate the density of the planet.

7. A cylindrical vase with a radius of 3m and 1m high is filled with oil with a density of 900 kg/m^3 if the atmospheric pressure is 1.03×10^5 N/m^2 and the acceleration of gravity 9.8 m/s^2 Calculate:

    a. Pressure of the oil on the bottom of the pot .

    b. Total pressure on the bottom of a pot .

8. Hydraulic piston with two cylinders half diameters (20,40) cm find the ratio between the two forces $F_2:F_1$.

$$P_1 + h_1 \rho g + \frac{1}{2} \rho v_1^2 = P_2 + h_2 \rho g + \frac{1}{2} \rho v_2^2 \quad (6.8)$$

This relationship is known as the Bernoulli equation, which can be formulated that at all points on the flow line, the amount $P + h \rho g + \frac{1}{2} \rho v^2$ remains constant.

If the fluid is static, i.e. $v_1 = v_2 = 0$, the Bernoulli equation is:

$$P_1 - P_2 = (h_2 - h_1) \rho g$$

This is the relationship between pressure and height within a static fluid. If the fluid is moving in a horizontal tube at one height, the Bernoulli equation is:

$$P_1 - P_2 = \frac{1}{2} \rho (v_2^2 - v_1^2)$$

For Bernoulli's equation are many applications such as perfume spray and planes wing design.

Example: 6.10

An irregular horizontal tube in which the water flows, so if the pressure 1332.8 P_a is in the part where the speed of the water is 0.5 $\frac{m}{s}$. Calculate the pressure in the part where the speed is 0.8 $\frac{m}{s}$.

Solution

$$P_1 - P_2 = \frac{1}{2} \rho (v_2^2 - v_1^2)$$

$$P_2 = P_1 - \frac{1}{2} \rho (v_2^2 - v_1^2)$$

$$= 1332.8 - \frac{1}{2} \times 10^3 \times [(0.8)^2 - (0.5)^2] = 1137.8 \ N/m^2$$

$$T_C = \frac{5}{9}(T_F - 32) \qquad (7.1)$$

To convert from the Kelvin scale to the Celsius scale, we use the relationship:

$$T_K = T_C + 273 \qquad (7.2)$$

Example: 7.1

If the room temperature on a summer day is 100 °F , then how much is it on the Celsius and on the Kelvin scale?

Solution

First on the Celsius scale:

$$T_C = \frac{5}{9}(T_F - 32)$$

$$= \frac{5}{9}(100 - 32) = 37.8°C$$

Second, on the Kelvin scale:

$$T_K = T_C + 273$$

$$= 37.8 + 273 = 310.8\ K$$

Example: 7.2

At what degree does the Fahrenheit thermometer reading become twice the Celsius thermometer?

Solution

If x is the Celsius thermometer, the Fahrenheit thermometer reading is $2x$.

$$\frac{x}{100} = \frac{2x - 32}{180}$$

$$180\,x = 100\,(2x - 32)$$

$$180\,x = 200\,x - 3200$$

$$200\,x - 180\,x = 3200$$

$$20\,x = 3200$$

$$x = \frac{3200}{20} = 160^{\circ}$$

That is, the Celsius thermometer reading at 160° will be 320 °F at Fahrenheit thermometer.

2. Thermal expansion

Figure 7.4: The effect of thermal expansion on railways and bridges

the vibration energy of the atoms in matter increases with increasing temperature, so an increase in the distance between atoms occurs and a change in the dimensions of the material results. So, in most case, the dimensions of the material is increases with increasing temperature and decreases with its decrease. This phenomenon is known as thermal expansion. In the case of the solid material the amount of expansion is very small, while in the state of fluids is large, and we find the expansion very large in the case of gases due to the difference in the bonding forces in each case of the material. Therefore, this phenomenon must be taken into consideration when constructing metal bridges, railways, gas pipelines and mineral fluids as in Figure (7.4).

1. Temperature scales

Temperature is a measure of a heat of the body. We often associate the concept of temperature with the amount of heat or cold that we feel when we touch an object. There are several temperature gauges known as thermometers. Thermometers exist in different types, but all depend on the principle of changing a physical property with temperature, such as:

1. Liquid volume at constant pressure.
2. Gas volume at constant pressure.
3. Gas pressure at a fixed volume.
4. The dimensions of the solid body.
5. Electrical resistance of the conductive material.
6. The radioactive wavelength has changed with the temperature of the hot body.

It is possible to design a thermometer that depends on any of the previous physical properties.

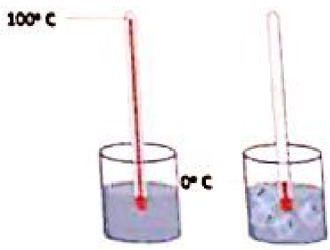


Figure 7.1: Centenary gradient divided by 100 degrees between freezing and boiling points of water

Celsius Scale

the scientist Celsius is invented this scale, in which he divides the range between two points into a hundred equal parts. The lower point is called the melting point of ice, and the upper point is the boiling point of water at standard atmospheric pressure, as shown in Figure 7.1.

Fahrenheit Scale

The Fahrenheit scale is relative to the scientist Fahrenheit, which considered the degree of freezing water at the standard atmospheric pressure is 32° Fahrenheit and the boiling point of water is 212° Fahrenheit, thus the difference between the two degrees is 180° Fahrenheit.

Kelvin Scale

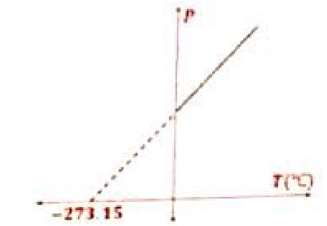


Figure 7.2: The relationship between pressure and temperature when volume is constant

The physicist Kelvin who used the international system for measuring temperature which is called by his name (Kelvin). The smallest point is the melting point of ice and given $273.15°K$. The greatest point is the boiling point of water and given $373.15°K$. The number of graduation sections is given by one hundred. Each section is called the degree of Kelvin. When the pressure of any system decreases when the volume is established, the temperature decreases until it reaches -273.15 degrees Celsius, as shown in Figure 7.2, so it is equal to zero degree on the absolute scale in Kelvin.

The relationship between thermometric scales

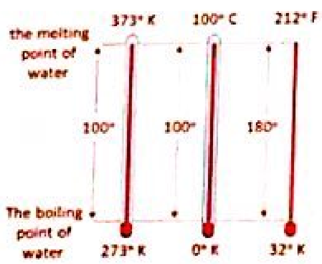


Figure 7.3: Various thermometers

The different thermometers are indicating a single temperature when placed in one medium. We are comparing of a different temperature scale for water in ice melts point and water boils point under the standard atmospheric pressure, as in Figure (7.3),

The following equation is used to convert from one of these scale to the other:

$$\frac{T_C}{100} = \frac{T_K - 273}{100} = \frac{T_F - 32}{180}$$

To convert from the Fahrenheit scale to the Celsius scale, we use the relationship:

$$l_2\, w_2\, h_2 = l_1\, w_1\, h_1\, [\, 1 + \alpha\, \Delta T\,]^3$$

$$V_2 = V_1\, [\, 1 + 3\, \alpha\, \Delta T + 3\, (\alpha\, \Delta T)^2 + (\alpha\, \Delta T)^3]$$

The last two parts may be neglected due to their small size and they are:

$$V_2 = V_1\, [\, 1 + 3\, \alpha\, \Delta T]$$

$$V_2 = V_1\, [\, 1 + \beta\, \Delta T] \qquad (7.5)$$

Note that the coefficient of volume expansion β equals three times the coefficient of linear expansion ($\beta = 3\alpha$).

Volume expansion coefficient β: defined as the relative change in slide size when the temperature changes by one-degree Kelvin.

Abnormal behaviour of water

The liquid takes the form of a container in which it is placed, and therefore the liquid only has a volume expansion coefficient. It is known to us that the fluids expand by the heat and increase in volume, but water is the only liquid that deviates from this base in a certain range of temperature. When we raise the temperature of a certain volume of water from $0°C$ to $4°C$, we find that the volume of water decreases rather than increases as in other liquids, and this decrease in volume continues until the water reaches a temperature, after which the volume of water increases with increasing temperature. That is, the volume of a certain amount of water is minimal when its temperature rises to $4°C$, as shown in Figure 7.6.

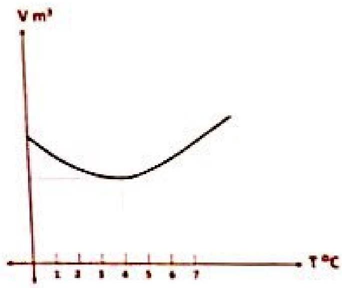


Figure 6.7: The volume of water changes with temperature degree.

This phenomenon called water anomaly is of great importance in cold regions where there is a layer of ice on the surface at zero degrees Celsius, while below this layer we find water at a temperature $4°C$ and thus aquatic organisms can live in this medium.

Example: 7.3

A length of copper bar is 10 m at zero Celsius, raising its temperature to $500°C$. calculate the following:

a. Final length of the copper bar.

b. The volume expansion coefficient of the copper.

Note that the coefficient of longitudinal expansion of copper α is equal to. $1.8 \times 10^{-5}\ C^{\circ\,-1}$

Solution

a. $\ell_2 = \ell_1 (1 + \alpha \Delta T)$

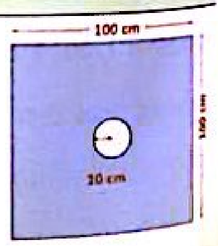
$= 10\,[1+(1.8 \times 10^{-5} \times 500)\,] = 10.09\ m$

b. $\beta = 3\,\alpha$

$= 3 \times 1.8 \times 10^{-5} = 5.4 \times 10^{-5}\ C^{\circ\,-1}$

Example: 7.4

Slice of metal in the form of a square, the length of its side 100 cm, in zero Celsius degree, in the middle of which there is a circular hole, half a drop 10 cm. If the length of the side of the square increases by 1 cm.



a. Calculate the temperature causing this increase.

b. Calculate the diameter of the hole after expansion.

Note that the longitudinal expansion coefficient $\alpha = 1.25 \times 10^{-5}\ C^{\circ\,-1}$.

slice temperature is raised to T_2 the length and width become w_2, ℓ_2, then the new dimensions of the slice become:

$$\ell_2 = \ell_1 \,(1 + \alpha\, \Delta T)$$

$$w_2 = w_1 \,(1 + \alpha\, \Delta T)$$

The slice area shall be $S_1 = \ell_1\, w_1$ before heating and $S_2 = \ell_2\, w_2$after heating

$$S_2 = \ell_2\, w_2$$
$$= S_1\,[\,1 + 2\,\alpha\,\Delta T + (\alpha\,\Delta T)^2]$$

The last term of the previous relationship can be neglected, because α is a small amount and therefore:

$$S_2 = S_1\,[\,1 + 2\,\alpha\,\Delta T]$$

$$S_2 = S_1\,[\,1 + \gamma\,\Delta T] \qquad (7.4)$$

Note that the coefficient of surface expansion γ equals twice the coefficient of longitudinal expansion ($\gamma = 2\alpha$).

Surface expansion coefficient γ: defined as the relative change in the area of a slide when its temperature changes by one-degree Kelvin.

Volume expansion coefficient

Suppose a solid box have dimensions w_1 , ℓ_1 , h_1 , at temperature T_1, and heated until it reaches a temperature T_2. We find that the size of the box increases due to the expansion of its dimensions to become its dimensions w_2، ℓ_2، h_2 after heating, Thus the size of the slide after heating is:

Longitudinal expansion coefficient

Suppose a metal bar as shown in Figure (7.5), the length of which is extended due to the increase in temperature. In practice, we found that the increase in length was directly proportional to the original length. Thus, the amount of increase in length is greater than the increase in both width and thickness. Suppose that the original length of the body is ℓ_1, and when the temperature is raised by an amount ΔT, we notice an increase in the length by the amount $\Delta\ell$. It has been found that the increase in length is directly proportional to the original length and temperature difference as follows:

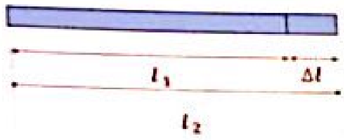


Figure 7.5: The effect of thermal expansion on a metal leg

$$\Delta\ell = \alpha\,\ell_1\,\Delta T$$

$$\ell_2 - \ell_1 = \alpha\,\ell_1\,\Delta T$$

$$\ell_2 = \ell_1\,(1 + \alpha\,\Delta T) \qquad (7.3)$$

Where ℓ_2 is the final length after stretching. The proportionality constant α is called the longitudinal expansion coefficient of the material.

Longitudinal expansion coefficient: α defined as the amount of change in length for each temperature change of one-degree Kelvin.

Surface expansion coefficient

When you raise the temperature of a slice of solid material, its length and width increase, so if the height and width before heating are w_1، ℓ_1, in order, at a temperature T_1, then if the

$$Q = C\,\Delta T \tag{7.7}$$

The amount of heat gained or lost can be calculated using the previous equation provided that the material does not change from phase to another. If the material is transformed from a phase to another, the previous relationship cannot be used during the transformation process, because the temperature during this process will remain constant, thus calculating the amount of heat gained or lost during the transformation process from the following relationship:

$$Q = m\,L \tag{7.8}$$

L is the latent heat that is known as the amount of heat needed to convert one gram of material from a phase to another phase, when the temperature is constant.

Example: 7.6

Calculate the amount of heat needed to change the 720 gm of ice at $-10^{\circ}\,C$ to $0^{\circ}\,C$. Note that the specific heat of the ice $c = 2220\ J/kg\,K$.

Solution

$$Q = m\,c\,\Delta T$$

$$= 0.72 \times 2220 \times [0-(-10)] = 15984\ J$$

Example: 7.7

A system of liquid water and ice with mass equal 720 gm is heated until the ice is completely melted, how much should it be gained during the presence of the liquid and ice phase in the system?

Note that the latent heat of the ice melt is 333 kJ/kg

Solution

$$Q = m\,L$$

$$= 0.72 \times 333 \times 10^{3} = 239760\ J$$

Example: 7.8

A 75 gm copper sample raised its temperature to $312^\circ C$, and then placed in a glass container (water temperature $12^\circ C$, and water mass 220 g). Calculate the final temperature of mixture, if the thermal balance is reached.

Note that the specific heat of copper is $0.092 \frac{Cal}{g \cdot K}$, the specific heat of water is $1 \frac{Cal}{g \cdot K}$, and the heat capacity of glass is $45 \frac{Cal}{K}$.

Solution

$$Q_{Copper} = Q_{Water} + Q_{glass}$$

$$[m_{Copper}\, c_{Copper}\, (T_i - T_f)] = [m_{Water}\, c_{Water}\, (T_f - T_i)] + [C_{glass}\, (T_f - T_i)]$$

$$75 \times 0.092\ (312 - T_f) = 220 \times 1\ (T_f - 12) + 45\ (T_f - 12)$$

$$2152.8 - 6.9\, T_f = 220\, T_f - 2640 + 45\, T_f - 540$$

$$5332.8 = 271.9\, T_f$$

$$T_f = 19.6\,°C$$

4. Heat transfer

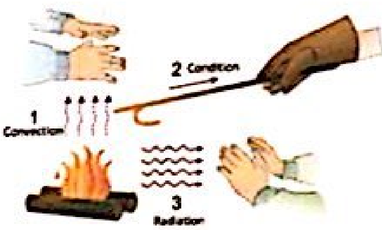


Figure 7.7: Heat transfer methods

Heat is transferred in three ways: conduction, load and radiation as described in the Figure (7.7)

Thermal Conduction

The amount of heat Q that passes through a layer of material has two flat and parallel surfaces and thickness x, directly proportional to the area of the surface A through which the heat passes, the difference between the temperature of the two sides of the layer T_1, T_2, the time of heat transfer t, and inversely proportional to the thickness of the layer x.

or lost by a system is proportional to its mass m and change in temperature of the ΔT:

$$Q \propto m \Delta T$$

The constant proportionality is called the specific heat of the material.

$$Q = c\, m \Delta T \quad (7.6)$$

Specific heat of material c is defined as the amount of heat needed to raise the temperature of one gram of the material 1°C.

The amount of heat is measured by the calorie, which is the amount of heat needed to raise the temperature of one gram of water 1°C.

The scientist joule has conducted an experiment in which he proved the possibility of converting thermal energy into mechanical energy and vice versa, thus proving that thermal energy or heat is only a type of energy can be expressed in joule units, if W is the work done by joule which resulted in the amount of heat Q calorie, then:

$$W\ (Joule) = J \times Q\ (Calorie)$$

Where a constant J called mechanical heat equivalent has been proven by practical experiments that:

1 Calorie = 4.18 Joule

Heat capacity is the amount of heat needed to raise the temperature of the material 1°C, and it is symbolized by the symbol C.

Solution

a. $\ell_2 = \ell_1 (1 + \alpha \Delta T)$

$$\Delta T = \frac{\ell_2 - \ell_1}{\ell_1 \ \alpha}$$

$$= \frac{101 - 100}{100 \times 1.25 \times 10^{-5}} = 800° \ C$$

b. $\ell_2 = \ell_1 (1 + \alpha \Delta T)$

$$= 20 \ (1 \ + \ 1.25 \ \times \ 10^{-5} \ \times \ 800) \ = \ 20.2 \ cm$$

Example: 7.5

A size of metal box is 0.55 m^3 at a temperature $20°C$. if the temperature increases to $100°C$, what is the box size after expansion?

Note that the coefficient of longitudinal expansion $\alpha = 1.7 \times 10^{-5} \ C^{\circ -1}$

Solution

$\beta = 3 \ \alpha$

$= 3 \ \times \ 1.7 \times 10^{-5} \ = \ 5.1 \ \times \ 10^{-5} \ C^{\circ -1}$

$V_2 = \ V_1 \ [\ 1 + \beta \ \Delta T]$

$= \ 0.55 \ [1 \ + \ (5.1 \times 10^{-5}) \ (100 - 20)] = \ 0.552 \ m^3$

3. Specific Heat

Heat is a type of energy like other types of energy such as kinetic energy, potential energy, electrical energy, chemical energy, and photovoltaic energy. If heat is generated, it is as much as the work involved in generating it. Energy in all its forms is conserved, i.e. it does not perish and is not created from nowhere, but it is transformed from one form to another. The energy conservation rule states that: the total energy in any closed system is conserved. an amount of heat Q acquired

Radiation

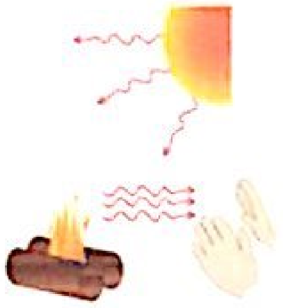


Figure 7.9: Heat transfer by radiation

Heat is transmitted by radiation outside the hot object, i.e through the surrounding medium, whether vacuum or physical medium and this is how heat travels from the sun to the Earth as shown in Figure (7.9). Heat radiation is electromagnetic waves that move at the speed of light, also all laws that apply to electromagnetic waves also apply to thermal radiation.

Scientist Stefan suggested that the total radiation from the body is proportional to the fourth exponent to its absolute temperature. Boltzmann was then able to theoretically prove Stefan's law of thermodynamics, and found that the law applied only to ideal black objects, and was called the Stéphane-Boltzmann rule, which states:

$$Q = \sigma A T^4 \quad (7.10)$$

Where:

Q : The total energy of radiation per second of square meters of a black object.

T : The absolute temperature of the surface(K).

σ : Stefan Boltzmann constant $\sigma = 5.67 \times 10^{-8}\ W/m^2 K^4$

A : The area of the radioactive surface (m^2)

Example: 7.9

A sheet of metal whose surface area 200 cm^2 and thickness 2 cm find the amount of heat that travels through the plate in a time of 1 min. if the difference in the temperature of the opposite surfaces is 100 °C and the thermal conductivity of the plate is 0.2 $\frac{Cal}{s.cm.°C}$

Exercises

1. Find the value of oxygen freezing temperature on a Celsius if its value -362 °F.
2. Calculate the value of temperature on the Fahrenheit when the temperature is on the Celsius equal -10 °C.
3. Find the amount of heat needed to convert $0.1\ kg$ from ice to water vapour (Note that the latent heat of fusion of water is $3.33 \times 10^5 \frac{J}{kg}$, the latent heat of vaporization of water is $2.26 \times 10^6 \frac{J}{kg}$).
4. If an amount of heat $Q = 150\ cal$ is given to 100 gm of aluminium and 100 gm of copper. Which one is hotter element?

   Not that: the specific heat of copper is $0.092\ \frac{cal}{gm \cdot K}$ and the specific heat of aluminium is $0.2\ \frac{cal}{gm \cdot °C}$.

5. A copper bar has a one-meter length and $2\ cm^2$ section area, one end of this bar is put in water its temperature 100 °C and the other end put in ice at 0 °C. Calculate how much heat is transferred from the hot end to the cold end in a time of 10 minutes.

   Note that: the coefficient of thermal conductivity of the bar is $0.2\ \frac{cal}{cm.s.°C}$.

6. What is the amount of heat released when $20\ gm$ of water cools from temperature 90 °C to 30 °C?

   Note that: the specific heat of water is $1\ \frac{cal}{gm \cdot °C}$.

7. An insulated aluminium container, its weight $20\ gm$ contains $150\ gm$ water at 20 °C. A piece of metal with mass $30\ gm$ was heated to 100 °C and then dropped into the water. If the final temperature of the water, the bowl and the piece of metal is 25 °C, find the specific heat capacity of the metal.

b. **Electrification of an uncharged object by contact with another charged object:**

If a conductive object charged with an electrical charge comes into contact with another uncharged conductive object (electrically equivalent), the conductive object charged as a result of the conduct loses part of its charge to the other equivalent conductor body, generating electrical charges of the same type. The total charge is distributed on them so that the total electrical charge remains constant.

c. **Electrifying an uncharged object without contact with another charged object:**

If a charged object approaches another electrically equivalent conductor object, the even object will be affected by the charged object, with two different charges. A shipment close to the moving object is contrary to its charge and is called a restricted charge. The shipment away from the moving object is similar to its shipment and is called a loose charge as in Figure (8-2).

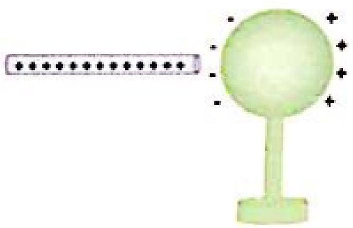


Figure 8.2: How to electrify by influence between a charged object and another neutral object.

2. Coulomb's Law

Scientist Charles Coulomb conducted many practical experiments in the laboratory to study the behavior of electrically charged objects, to determine the relationship between the amount of electrical charges and the amount of attractive force and repulsive between them. The scientist Coulomb relied on the concept of point charge in his study and experiments, where we consider the body charge to be

$$Q \propto A \frac{T_1 - T_2}{x} t$$

The proportionality constant is called a thermal conductivity coefficient k_c

$$Q = k_c A \frac{T_1 - T_2}{x} t$$

$$H = k_c A \frac{T_1 - T_2}{x} \quad (7.9)$$

The amount $H = \frac{Q}{t}$ is called the heat transfer rate, and the amount $\frac{T_1 - T_2}{x}$ is called temperature gradient. The thermal conductivity coefficient k_c is measured by a unit $\frac{J}{s.m.K}$

Thermal conductivity factor k_c: Defines as the rate of heat transfer through a layer of two parallel surfaces, the area of its section is 1 m^2 and has a thermal gradient 1 $\frac{K}{m}$.

Convection

Heat is transferred by the movement of molecules from hot to cold positions carrying thermal energy, when these molecules collide with other molecules, we see the spread of heat through fluid, and this occurs only in the case of fluids. For example, heat transfer through water, when heated, the water near the bottom is hotter than above it and therefore its density decreases, as a result the hot water rises up and cold water falls downwards. In other words, convection is the movement of hot liquid during the pot as in the Figure (7.8).

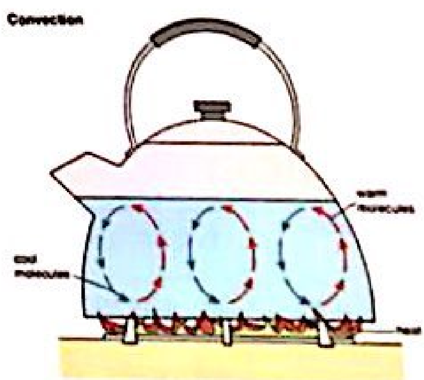


Figure 7.8: Heat transfer by convection

1. Properties of Electric Charges

In Nature there are two types of electrical charges, the first being negative charges such as those carried by the electron and others positive charges such as proton charges. An object can be shipped by transferring some electrons from one substance to another substance with the massage, thus generating on the material from which the electrons are transmitted a positive charge $Q = +N\,e$, and the material to which the electrons moved is generated a negative charge $Q = -N\,e$, and these charges generated are equal to the true number n of a single electron charge estimated at 1.6×10^{-19} C. The electrical charge measurement unit is the C- Coolum.

Ways to get a charged body:

a. Electrification of an uncharged object with friction with another object:

When two electrically equivalent objects come into contact from two different substances, some valence electrons (the last orbit electrons in an atom) move from one object to the other. The number of electrons lost by one body is exactly the same as the number of electrons that the other body acquires. In this way, we have shipped the bodies with two charges of equal amount and different in type. For example, a rod of Aponite was charged with a negative charge when a piece of wool cloth was massaged, as well as a glass rod with a positive charge when it was massaged with a piece of silk cloth as shown in Figure (8.1).

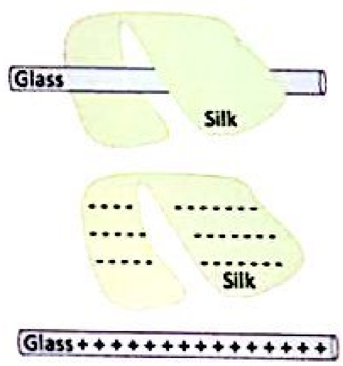


Figure 8.1: How to charge a glass stem by rubbing it with a piece of silk.

Chapter 8 :

Static Electricity

1. Properties of electric charges
2. Coolum›s law
3. Electric field
4. Electric Potential
5. Capacitors

Static electricity has many applications in our daily lives, including laser printers, electrocution and paper cameras. We will study the basic concepts of point electrical charge, Coolum›s law, electric field, electric voltage, and at the end of the chapter we will study the capacitors.

$$F_{CA} = k_e \frac{q_A \cdot q_C}{r^2}$$

$$= (9 \times 10^9) \frac{(3 \times 10^{-6}) \cdot (12 \times 10^{-6})}{(0.05)^2} = 129.6 \text{ N}$$

The direction of this force in the negative direction of the (x) axis.

So, the result of the two forces F_A is:

$$F_A = F_{BA} - F_{CA} = 337.5 - 129.6 = 207.9 \text{ N}$$

The force obtained is in the positive direction of (x) axis.

3. Electric field

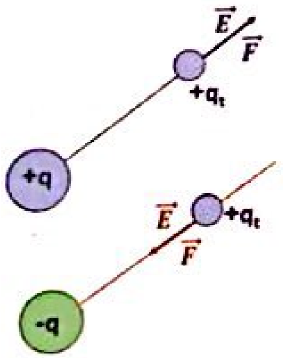


Figure 8.5: Shows the direction of the electric field strength of a positive and negative charge

The Electric Field, which is generated by an electrical charge, can be defined as the space around that charge in which its effect appears.

The electrical field at a point: is defined as the electrical force affecting a positive point-test charge of the unit placed at that point.

To calculate the power field strength of a q charge at a point far away r. We suppose that a small positive q_t test charge placed at that point. Charge Q affects the test charge q_t with F force, calculated by the Coolum law

$$F = k_e \frac{q \cdot q_t}{r^2}$$

Thus, the electric field is equal to:

$$E = \frac{F}{q_t} = k_e \frac{q}{r^2} \quad (8.2)$$

Not that: the specific heat of aluminium is 0.21 $\frac{cal}{gm\cdot°C}$ and the specific heat of water 1 $\frac{cal}{gm\cdot°C}$.

8. What is the amount of heat required to convert 30 gm from ice at a -5 °C to water its temperature 20 °C?

Note that: the specific heat of water 1 $C\frac{cal}{gm\cdot°C}$, the specific heat of ice 0.5 $\frac{cal}{gm\cdot°C}$, the latent heat of melting ice 80 $\frac{cal}{gm}$.

9. The copper calorimeter has a specific heat 0.20 $\frac{cal}{gm\cdot°C}$, and its mass 70 gm contains 400 gm water and 100 gm ice in a state of thermal equilibrium. Added to the contents of the calorimeter is a hot piece of metal whose specific temperature 0.1 $\frac{cal}{gm\cdot°C}$, mass 300 gm, and temperature is unknown, if the final temperature of the mixture is 10 °C. What is the initial temperature of the metal?

Note that the latent heat of melting ice is 80 $\frac{cal}{gm}$ the specific heat of water 1 $\frac{cal}{gm\cdot°C}$.

10. A copper rod, with a section area of 2 cm^2 and one-meter length. one end of this rod is put in boiling water at 100 °C and the other end put on a plate of ice at 0 °C. Calculate the amount of heat that moves from the hot end to the cold end in a time of 10 minutes.

Note that: the coefficient of thermal conductivity of copper is 0.2 $\frac{Cal}{cm.s.°C}$.

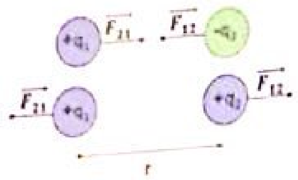


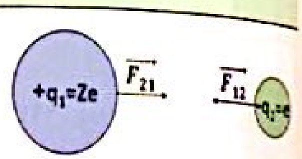
Figure 8.4: shows the direction of the gravitational forces and the forces of electrical repulsion between charges.

It should be noted that the direction of electrical force between similar charges is outward (repulsive force), while the direction of the electrical force between the different charges inward (attractive force) as shown in Figure (8.4). Electrical force is measured by newton. The proportionality constant in the previous relationship is called the Coulomb constant (k_e). This constant depends on the permittivity of free space (ε_o). The value of the coulomb's constant vacuum is equal to:

$$k_e = \frac{1}{4\pi\varepsilon_o} \cong 9 \times 10^9\, N \cdot m^2/C^2$$

Example: 8.1

Find the amount of electrical force between the charge of the nucleus of the sodium atom and the electron in one of the orbits of the atom away from the nucleus $1.2 \times 10^{-11}\, m$. Atomic number of sodium Z=11.



Solution

The forces between the nucleus of the sodium atom and the electron are attractive force.

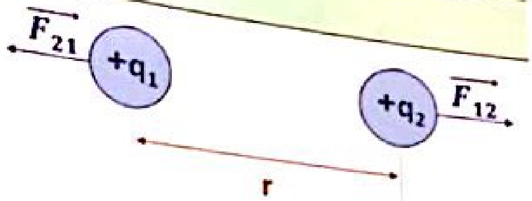
$$F = k_e \frac{q_1 \cdot q_2}{r^2}$$

$$= (9 \times 10^9) \frac{(11 \times 1.6 \times 10^{-19}) \times 1.6 \times 10^{-19}}{(1.2 \times 10^{-11})^2} = 1.76 \times 10^{-5} N$$

Example: 8.2

Find the amount of electrical charge affecting another positive charge of 5μC and 25 cm away from both are putting in the vacuum, with the electrical force between them equal to 2.4 N for the outside, and determine the type of unknown charge.

$$F_{12} = k_e \frac{q_1 \cdot q_2}{r^2}$$



$$q_1 = \frac{F_{12} \cdot r^2}{k_e \cdot q_2}$$

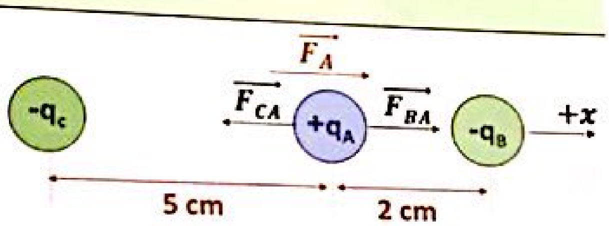
$$= \left(\frac{2.4 \times (0.25)^2}{(9 \times 10^9)(5 \times 10^{-6})}\right)$$

$$= 3.33 \times 10^{-6} C$$

Since the force is out (repulsive) the two charges are similar, and from there we find that the required charge is positive.

Example: 8.3

Calculate the magnitude and direction of the force affecting the point charge placed at point A. Note that the amount of charges is: ($q_A = 3\mu C$, $q_B = 5\mu C$, $q_C = 12\ \mu C$)



Solution

First, we calculate the magnitude of force by which charge B affects charge A.

$$F_{BA} = k_e \frac{q_A \cdot q_B}{r^2}$$

$$= (9 \times 10^9) \frac{(3 \times 10^{-6}) \cdot (5 \times 10^{-6})}{(0.02)^2} = 337.5 \text{ N}$$

The direction of this force in the positive direction of the (x) axis.

Second, we calculate the amount of force by which charge C affects charge A.

Electrical voltage for point charge

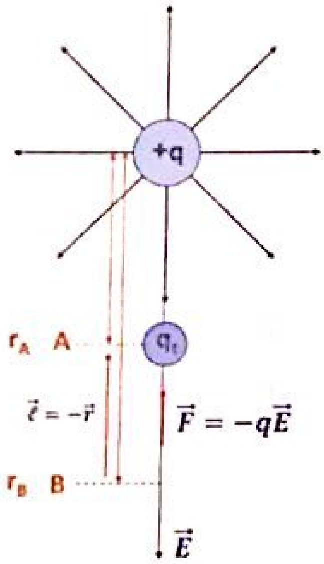


Figure 8.8: Voltage of the positive point charge

The voltage difference between two points B and A in the electric field for a positive point charge along the line between the two points and the center of the charge is shown in Figure (8.8), where the electric field of the positive point charge spreads outward in all directions, so the field is irregular in the surrounding area of the charge. The voltage difference between the two points is calculated in the irregular field from the relation:

$$\Delta V = V_{AB} = V_A - V_B = -\int_{\ell_B}^{\ell_A} \vec{E} \cdot d\vec{\ell}$$

Where $d\vec{\ell}$ is a differential element of the displacement vector that the charge q_t moved in the electrical field from point B to point A, this vector is the opposite direction of the vector $\vec{E}$, so:

$$d\vec{\ell} = -d\vec{r} \quad , \quad \vec{\ell_A} = -\vec{r_A} \quad , \quad \vec{\ell_B} = -\vec{r_B}$$

By compensating for the electric field vector $\vec{E}$ in the equation:

$$\vec{E} = k_e \frac{q}{r^2} \hat{r}$$

Where $\hat{r}$ represents a unit vector in the direction of the electrical field.

$$\Delta V = -\int_{-r_B}^{-r_A} k_e \frac{q}{r^2} \hat{r} \cdot (-d\vec{r}) = k_e q \int_{-r_B}^{-r_A} \frac{dr}{r^2}$$

concentrated at a physical point without dimensions (some references are called particles).

Electrical power is divided into two types:

a. The Power of Repulsion

If a rod of the glass charged with a positive charge is suspended and left free to move as in Figure (8.3), then another rod is rounded from the glass charged with a positive charge of the suspended rod. Note that the free-moving suspended rod begins to move and rotate away from the other rod. We conclude from this that objects charged with similar kinds are incompatible.

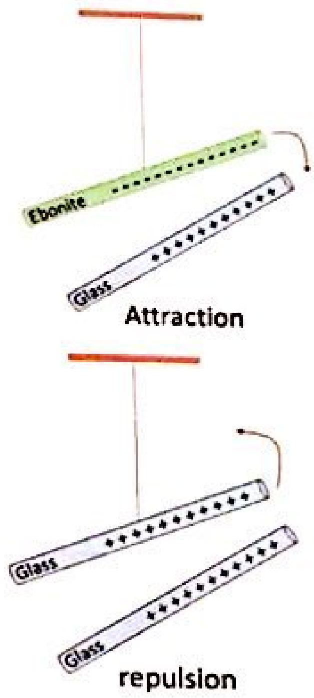


Figure 8.3: shows the forces of repulsion between similar electrical charges, and the forces of attraction between different electric charges.

b. The power of Attraction

If a rod of aboniet charged with a negative electrical charge is suspended and left free-to-move as in Figure (8.3), then another rod is rounded from the glass charged with a positive charge of the suspended rod. Note that the free-moving suspended rod begins to move and rotate closer to the other rod. From this, we conclude that objects charged with different kinds of charges are attracted.

Coulomb's Law: States that the magnitude of electrical force between two charged particles is directly proportional to the product of multiplying the amount of two charges (q1.q2) and inversely with the square of the distance between them (r^2)

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

$$F = k_e \frac{q_1 \cdot q_2}{r^2} \qquad (8.1)$$

Let's start calculating the amount of voltage difference between points A and B by the force $\vec{F} = -q\vec{E}$ which calculated as:

$$W = \vec{F} \cdot \vec{d}$$

$$= -q_t\vec{E} \cdot \vec{d} = q_t E d$$

Clearly, the voltage at point A is higher than the voltage at point B, and from the definition of the voltage difference of the potential VoltageΔV:

$$\Delta V = V_A - V_B = \frac{W}{q_t} \quad (8.3)$$

$$\Delta V = \frac{q_t E d}{q_t}$$

$$\Delta V = Ed \quad (8.4)$$

The voltage or voltage difference is measured by a unit called volt v.

$$1\,V = \frac{1\,J}{1\,C}$$

Example: 8.5

Calculate the voltage difference between capacitive plates where the distance between the plates is 0.2 cm, if the electric field strength inside the capacitor is equal to 1000 $\frac{N}{C}$.

Solution

$\Delta V = Ed$

$= 1000 \times 0.002 = 2\,V$

energy as a result of the mechanical work exerted on it to raise it and is equal to mgh . Similarly, when a work W is exerted by an external $\vec{F}$ force to transport a positive small electrical test charge q_t in electric filed E. The test charge is moves displacement $\vec{d}$, from point B to point A. This charge acquires an electrical position energy, as is clear from Figure 8.7.

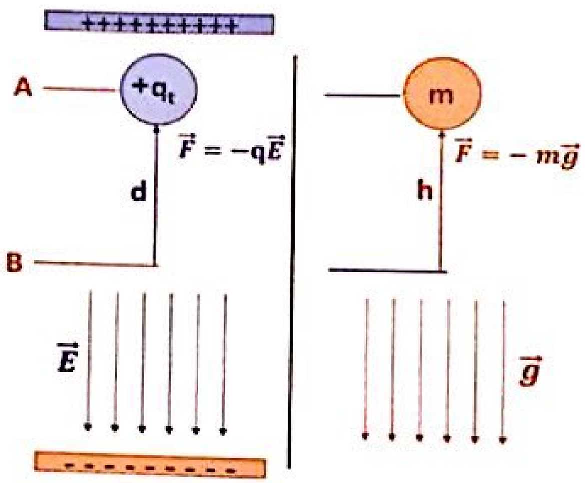


Figure 8.7: shows a comparison between the gravitational field and its effect on objects. The intensity of the electric field and its effect on the charges.

Electric Potential V at a point: is known as the amount of work exerted to moving the small positive electrical charge equal to unity, from infinity to these point in reverse direction to the electrical field.

The voltage difference ΔV between two points is defined by the amount of work exerted to moving the small positive charge equal to unity, between these two points in reverse direction of the electrical field.

The direction of the electric field vector is the same as the direction of the electrical force in which the q charge affects the test charge q_t as shown in Figure (8.5), and the electric field is measured by $\frac{N}{C}$.

Electric Field Lines

Now we are visualized the electrical field with a schematic representation. The best way to visualize electric field models is to draw lines known as electric field lines. The first to introduce this idea was the scientist Faraday. The numerical density of the electric field lines is proportional to the magnitude of the electric field. The electric field lines go outward from positive charges, and inbound to negative charges as shown in Figure (8.6).

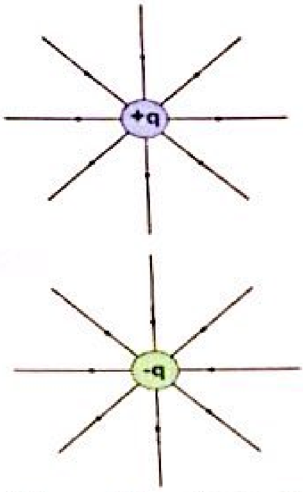


Figure 8.6: shows the direction of the electric field lines of positive and negative charges

Example: 8.3

Find the magnitude of the electric field at a point 5 m away from a positive point charge of 10 μc.

Solution

$$E = k_e \frac{q}{r^2}$$

$$= 9 \times 10^9 \frac{10 \times 10^{-6}}{5^2} = 3600 \frac{N}{C}$$

4. Electric Potential

The potential energy of an object in the field of gravity is clearly similar to the power of the electrical position of a charged object located in an electric field. When the object of a mass m is raised to a distance h vertically on the surface of the earth, we say that this object has gained some potential

Solution

$$C = \frac{\varepsilon_o A}{d}$$

$$= \frac{(8.85 \times 10^{-12}) \times (0.1 \times 0.1)}{0.002} = 4.42 \times 10^{-11}\ F$$

Connecting the capacitors

Capacitors can be connected in different ways, in order to obtain large or small values compared to the original values of the available capacitors capacitance.

Connect the capacitors in series

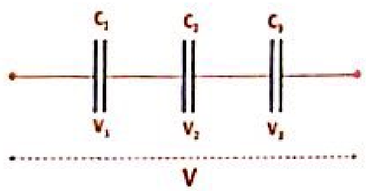


Figure 8.10: shows the connection of three capacitors in series

Capacitors are connected in series to obtain a small total capacitance less than the smallest capacitor in the circuit. If we have a group of capacitors connected in series and their capacitances are C1, C2 and C3 and a V voltage difference is applied to them as in Figure (8.10). As all capacitors will be charged with the same value of the electrical charge, we notice that:

$$V = V_1 + V_2 + V_3$$

$$Q = Q_1 = Q_2 = Q_3$$

Compensating for the potential difference from the relationship (8-6):

$$\frac{Q}{C_{eq}} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$

By dividing by (Q) we find:

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \qquad (8.8)$$

Parallel-Plate Capacitors

Parallel-plate capacitors consist of two parallel plates metal. The area of capacitors plates is A, separating the two plates from a distance d as shown in Figure (8-9). An isolated material is placed between the capacitor plates.

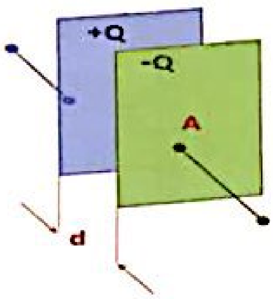


Figure 8.9: shows the installation of an electrical capacitor consisting of two metal plates

The capacitor capacitance is directly proportional to the capacitance plate area and inversely to the distance between the capacitor plates:

$$C \propto \frac{A}{d}$$

The proportionality constant depends on the nature of the isolation medium between the capacitor plates. When the isolation medium is the vacuum, the proportionality constant is the electrical permittivity of the vacuum.

$$\varepsilon_o = 8.85 \times 10^{-12}\ \frac{C^2}{N.m^2}$$

$$C = \frac{\varepsilon_o A}{d} \qquad (8.7)$$

so, the capacitance of any capacitor depends only on the dimensions of the capacitor and the type of dielectric between the capacitor plates only.

Example: 8.7

Parllel plates capacitor has a surface dimension of 10 cm x 10 cm, and the distance between plates is 0.2 cm. Calculate the capacitance of the capacitor if you know that the isolation medium between the capacitor plates is the vacuum.

The total voltage resulting at the P point

$$V_P = V_{q_1} + V_{q_2}$$

$$= -3 \times 10^5 + 11.23 \times 10^5 = 8.23 \times 10^5\ V$$

5. Capacitors

Capacitors are constructed in the simplest form of two surfaces of a conductive material between them a dielectric. The capacitor is an important element in electrical and electronic circuits as it is used in storing electrical energy in most of its connection cases. It is also used in alternating current circuits and resonance and filter circuits and many uses.

When the capacitor is connected to a constant voltage source, electrical charges accumulate on the capacitor plates, so that the amount of electrical charge stored on the capacitor is proportional to the amount of voltage difference on both ends of the capacitor:

$$Q \propto V$$

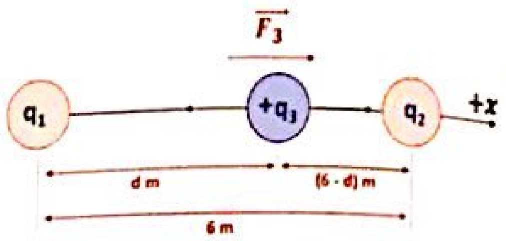
$$Q = C\,V \tag{8.6}$$

Capacitance C: defined as the amount of electrical charge accumulated on the capacitor plate when a unit difference of voltage is applied to it, measured in units of Farad F.

$$1\ F = \frac{1\ C}{1\ V}$$

Exercises

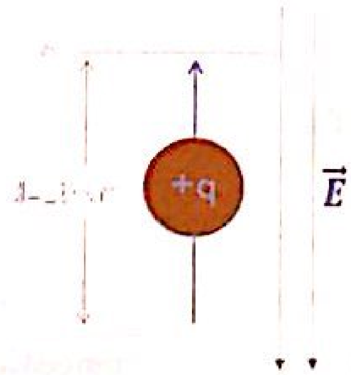
1. Two electric charges of $q_1 = 3 \times 10^{-5}$ C , $q_1 = 3 \times 10^{-5}$ Cand the distance between them 6 m were placed in a vacuum. Find the location at which the electrical power on the positive charge q_3 is zero.



2. Find the electric field affecting the point at a distance of 3.5 cm from the positive point charge of + 2μC and it was placed in a vacuum. Draw the direction of the field lines of that charge?

3. Calculate the electrical force affected by a point charge of + 10μC on a point charge of -6μC, placed in a vacuum, and the distance between them is 0.5 cm. Explain if it is an attraction or repulsive force.

4. When moving a positive electric charge of 25μC between two points, the distance between them 10cm in a regular electrical field parallel to the line connecting the two points, and in the direction of reversing the charge's movement, its electric power capacity increased by 4 mJ. Find the difference in voltage between the two points and the intensity of the affecting electric field?



5. Calculate the voltage of an 8μC point charge, placed in a vacuum, at a point 1 m away from it.

6. Calculate the capacitance of a plate area of 0.1 m^2, the distance between them 0.01 m, isolated into a vacuum. Electrical permittivity of vacuum $\varepsilon_o = 8.85 \times 10^{-12} \frac{C^2}{N.m^2}$.

$$= k_e q \left(-\frac{1}{r}\right)\Big|_{-r_B}^{-r_A} = k_e q\left(\left(-\frac{1}{-r_A}\right) - \left(-\frac{1}{-r_B}\right)\right)$$

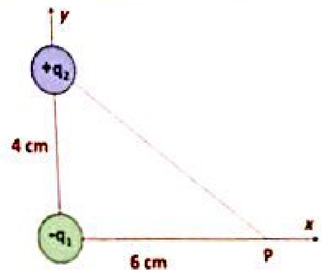
$$= k_e \frac{q}{r_A} - k_e \frac{q}{r_B}$$

When the charge is moved from the infinity $r_B = \infty$ to the point $r_A = r$ the voltage at this point is calculated from the relationship:

$$V = k_e \frac{q}{r} \qquad (8.5)$$

Example: 8.5

In the corresponding Figure, the charge q_1 = - 2 μC located at the origin point 4cm from which the charge q_2 = + 9 μC was placed on the y axis. Find the total voltage generated by these charges at point P, which is located on the x axis and 6 cm away from the origin point.



Solution

The voltage at the P point resulting from the q_1 charge is equal:

$$V_{q_1} = k_e \frac{q_1}{r_{q_1}}$$

$$= (9 \times 10^9)\frac{(-2 \times 10^{-6})}{0.06} = -3 \times 10^5\ V$$

The voltage at the P point resulting from the q_2 charge is equal:

$$V_{q_2} = k_e \frac{q_2}{r_{q_2}}$$

$$= (9 \times 10^9)\frac{(9 \times 10^{-6})}{\sqrt{(0.06)^2 + (0.04)^2}} = 11.23 \times 10^5\ V$$

Connecting capacitors in parallel:

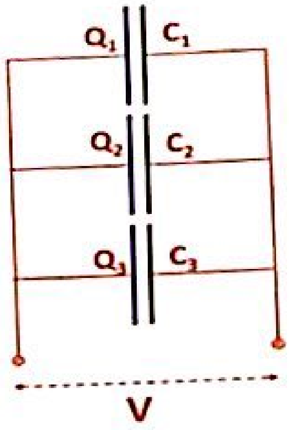


Figure 8.11: shows the connection of three capacitors in parallel.

Capacitors are connected in parallel to obtain a large total capacitance equal to the sum of the capacitance of capacitors connected in parallel in the circuit. If we have a group of capacitors connected in parallel whose capacities are C1, C2 and C3 and a difference of voltage V is applied to them as shown in Figure (8.11). Note that the voltage difference on the three capacitors is equal to the source voltage:

$$V = V_1 = V_2 = V_3$$

The total charge is distributed among the three capacitors according to the capacity of each capacitor, so that:

$$Q = Q1 + Q2 + Q3$$

By compensation for the charge of each capacitor from the Equation (6.8):

$$C_{eq}\, V = C_1\, V + C_2\, V + C_3\, V$$

By dividing by (V), we find that:

$$C_{eq} = C_1 + C_2 + C_3 \qquad (8.9)$$

The electrical energy stored in the capacitor

Suppose that the charge on the two surfaces of the capacitor at some instant is Q, and the voltage difference between the two surfaces is V. If a small charge dQ passes between the two surfaces of the capacitor via the difference in voltage V, the necessary work for this is:

a. First find the capacitance of the capacitors group C1 and C2 connected in parallel:

$C_{12} = C_1 + C_2 = 6 + 6 = 12\ \mu F$

Total capacitance $(C_{12} = C_1 + C_2)$ connected with capacitor C_3 in series

$$\frac{1}{C_t} = \frac{1}{C_{12}} + \frac{1}{C_3} = \frac{1}{12} + \frac{1}{12} = \frac{2}{12}$$

$$C_t = \frac{12}{2} = 6\ \mu F$$

b. The total electrical charge is calculated from:

$$Q_t = C_t \cdot V_t = (6 \times 10^{-6}).(50) = 3 \times 10^{-4}\ C$$

c. To calculate the electrical charge on each capacitor, we find the voltage difference first on each capacitor.

The total voltage difference will be distributed evenly over the capacitor obtained C_{12} and the capacitor C_3 because they are connected in series and equal in capacitance $C_{12} = C_3 = 12\mu F$. If the voltage difference on them is $V_3 = V_{12} = 25$ volt The first and second capacitors are connected in parallel, that is, the voltage difference is equal in both capacitors:

$$V_1 = V_2 = 25 \text{ volt}$$

The electrical charge on each capacitor:

$$Q_1 = C_1 \cdot V_1 = (6 \times 10^{-6}).25 = 1.5 \times 10^{-4}\ C$$
$$Q_2 = C_2 \cdot V_2 = (6 \times 10^{-6}).25 = 1.5 \times 10^{-4}\ C$$
$$Q_3 = C_3 \cdot V_3 = (12 \times 10^{-6}).25 = 3 \times 10^{-4}\ C$$

$$dW = V.dQ \quad \rightarrow \quad W = \int V.dQ$$

Compensating for the voltage difference from the Equation (86):

$$W = \int_0^Q \left(\frac{Q}{C}\right).dQ = \frac{1}{C}\int_0^Q Q.dQ = \frac{1}{2}\frac{Q^2}{C}$$

The work done of charging the capacitor is equal to the energy stored in the capacitor.

$$U = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}V^2.C = \frac{1}{2}Q.V \qquad (8.10)$$

Example: 8.8

capacitor has a capacitance of 20 μF, and the difference in voltage between the two terminals is 1000 V. Calculate the electrical energy stored in it.

Solution

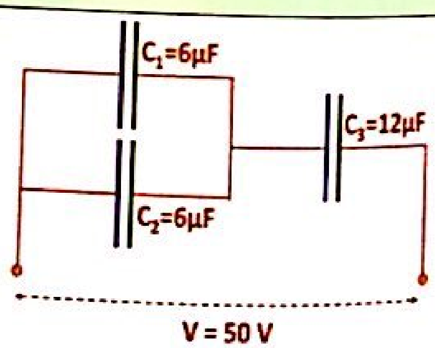
$$U = \frac{1}{2}V^2.C$$

$$= \frac{1}{2}(1000)^2.(20 \times 10^{-6}) = 10\,J$$

Example: 8.9

Three capacitors connected, as shown in the Figur

a. Calculate the total capacitance in the circle.
b. Calculate the total electrical charge.
c. Calculate the electrical charge generated on each capacitor.



If electrical charges move in an electric circuit from the positive voltage end to the negative voltage end through a regular-form conductor, then free electrons will move at a speed (v) in a direction that reverses to the direction of the electrical field (E)

If the numerical density of free electrons in the volume unit of the conductor is n, the amount of charge that passes through the wire section (A) in the time period Δt is equal to:

$$\Delta q = n\,e\,v\,A\,\Delta t$$

From the definition of the current we find that:

$$I = n\,e\,v\,A \tag{9.2}$$

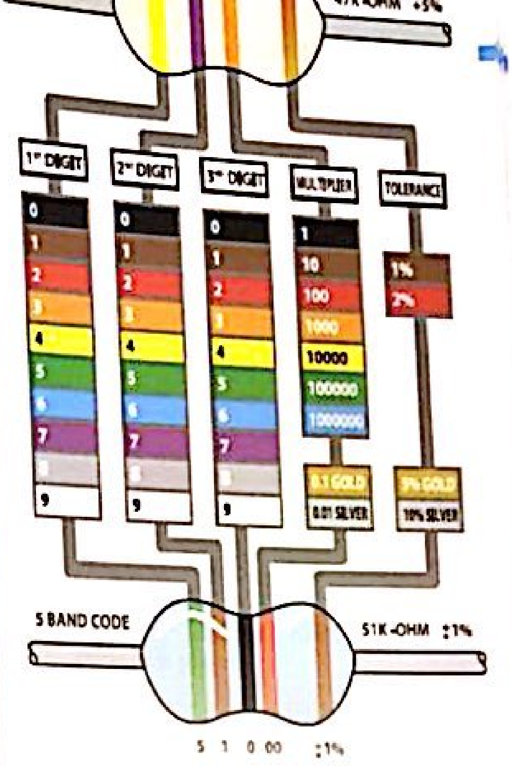
The density of the electric current (J) is defined as the amount of electricity passing through the vertical unit area of the conductor cross-section.

$$J = \frac{I}{A} = n\,e\,v \tag{9.3}$$

It should be noted that the density of free electrons (n) in an element in which each atom shares a single free electron is given in the equation:

$$n = \frac{\rho\,N_A}{A}$$

Where ρ the density of the element, A mass number, $N_A = 6.02 \times 10^{23}$ is the Avogadro number.



Chapter 9 :

Current and Resistance

1. Electric Current
2. Ohm›s Law
3. Electric Power
4. Connecting resistors

This chapter is concerned with studying the movement of electrical charges. We will study how the electric current flows and the factors that affect it, and the factors that impede its movement, and we will learn about Ohm›s Law and know the specific resistance and electrical conductivity of materials, electrical work and electrical power, and at the end of the section we will study electrical resistances and how to connect them in electrical circuits.

1. Electric current

Unrestricted electrical charges (negative or positive) move from one place to another due to their impact on an electrical field (E) caused by a difference in voltage between the two positions. The movement of these charges is called the electric current, which is a standard quantity. In conductive substances such as copper and aluminum, there are too many free electrons, i.e. they are not bound by their atoms. Free electrons are affected by electrical force if placed in an electric field, if the conductor is in the form of a closed trajectory, the electron moves, causing the electric current.

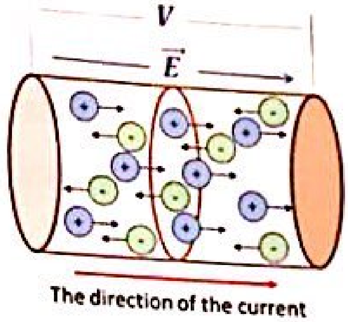


Figure 9.1: The movement of positive charges and the direction of the electric current is placed.

Electric current is defined as the rate at which charge which charge flows through this surface, in another word, it is defined as that amount of electrical charge Δq that passes through a section of the conductor per unit time.

$$I = \lim_{\Delta t \to 0} \frac{\Delta q}{\Delta t} = \frac{dq}{dt} \qquad (9.1)$$

The unit the current is ampere A.

$$1\,A = \frac{1\,C}{1\,s}$$

Example: 9.1

How much electrical current is generated by the passage of an electrical charge of 10 C in a 50-ms time period .

Solution

$$I = \frac{\Delta q}{\Delta t} = \frac{10}{50 \times 10^{-3}} = 200A$$

Solution

We find the amount of resistance before and after doubling the length and radius as follows:

We first find the resistance of the wire before the change as a function in length (L) and radius (r)

$$R = \rho\frac{l}{A} = \rho\frac{l}{\pi r^2}$$

Then we find the resistance of the wire after doubling the length (2L) and doubling the radius (2r)

$$R = \rho\frac{l}{A} = \rho\frac{2l}{\pi(2r)^2} = \rho\frac{2l}{4\pi r^2} = \rho\frac{l}{2\pi r^2}$$

From the above equations, resistance decreases and amounts to half of its amount before the change, and this by calculates the ratio between the two resistances before and after the change.

Example: 9.5

Nickel chrome alloy wire1 m long, 0.2 mm diameter, and its quality resistance $1 \times 10^{-6}\ \Omega \cdot m$

a. Calculate the resistance of the wire.

b. If the voltage difference of 20 V between the ends of the wire is affected. How much current is passing?

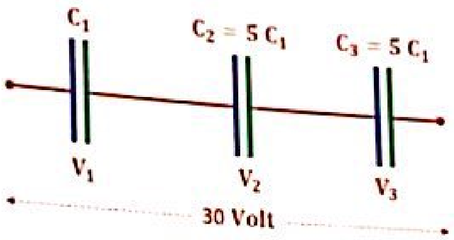
Solution

a. $R = \rho\frac{\ell}{A} = \rho\frac{\ell}{\pi r^2}$

$$= (1 \times 10^{-6})\frac{1}{\pi(0.2\times10^{-3})^2} = 7.96\ \Omega$$

b. $I = \frac{V}{R}$

7. Three capacitors, the second capacitor's capacitance and the third capacitor's capacitance are equal five times the first capacitor's capacitance. These capacitors respectively connected to a voltage source 30 volt. Find the voltage difference between the ends of each capacitor.



8. Two capacitors were connected in series in a circuit, so the total electrical capacitance was 10μF. On their parallel connection again, the total electrical capacitance was 45 μF. Calculate the capacity of each capacitor individually?

9. Three capacitors connected in series, if each capacitor's capacitance is equal to 10 μF calculate their total capacitance.

2. Ohm's law

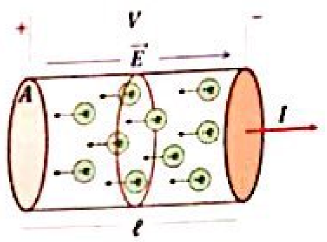


Figure 9.2: The effect of the potential difference on the current passing through the conductor.

The current passing through a conductor is proportional to the electrical field between the two conductor ends when its temperature is constant, and this law is called the Ohm's Law.

$$J \propto E$$

$$J = \sigma E$$

Where the proportionality constant in the previous relationship is called electrical conductivity σ, the value of electrical conductivity determines the nature of the material in terms of electrical conductivity. There are conductive, semi-conductive and insulation materials. Electrical conductivity corresponds to another quantity called specific resistance to the material ρ:

$$\rho = \frac{1}{\sigma}$$

The specific resistance ρ is associated with the conductor resistance R, which originates from the free electron movement within the conductive material, and is accompanied by the loss of energy as a result of collisions with conductor atoms, manifested in the form of heat energy. The electrical resistance is directly proportional to the length of the conductor and inversely proportional to the area of the conductor cross section.

$$R = \rho \frac{\ell}{A} \qquad (9.4)$$

We are now trying to write the Ohm's law in another practical form, illustrating the relationship between the voltage difference V between the two ends of the conductor and the current I pass through it. We assume we have a conductor with length L and a cross section area A, as in Figure (9.2). From the Law of Ohm we find that:

$$E = \frac{J}{\sigma} = \frac{I}{\sigma A} = \frac{\rho I}{A}$$

When the conductor is connected to a voltage difference of V between the ends, an electrical field arises within the conductor:

$$V = E \cdot \ell$$

$$V = \frac{\rho I}{A} \ell = RI$$

$$V = R\, I \qquad (9.5)$$

This means that the voltage difference between the two ends of a conductor is directly proportional to the intensity of the electrical current passing through it, when its temperature is constant. This is another version of the Ohm law.

Electrical resistance is measured by the ohm Ω.

$$1\,\Omega = \frac{1\,V}{1\,A}$$

Example: 9.4

Cylindrical wire in the shape of a radius of r and L long. If each of its length and radius is doubled, do the wire resistance:

a. Increase.
b. Decreased.
c. Stay the same.
d. Unrecognizable.

$$I_1 = I_2 = I_3 = I$$

Compensation for the voltage difference of the Ohm's Law:

$$R_{eq}\, I = R_1\, I + R_2 I + R_3 I$$

$$R_{eq} = R_1 + R_2 + R_3 \qquad (9.7)$$

Example: 9.7

Three resistances amounting to 18 Ω, 12 Ω, 6 Ω connected in series, how much of the equivalent resistance?

Solution

$$R_{equ} = R_1 + R_2 + R_3$$

$$= 18 + 12 + 6 = 36\Omega$$

Connecting resistors in parallel

The resistance is linked so that the end of all resistors is together and begins together as well, as shown in the Figure (9.4). The characteristics of this type of connection include:

1. The voltage difference is equal to all resistor and equal to the total voltage difference.
2. The electric current is distributed to the resistors.

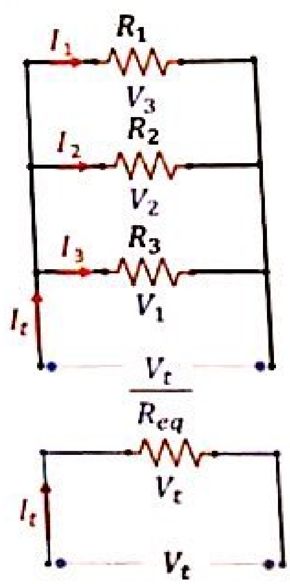


Figure 9.4: The resistors are connected in parallel.

Note that: the total current is equal to the sum of currents passing through all resistor:

$$I_t = I_1 + I_2 + I_3$$

Since the voltage difference is the same for all resistor and equal to the total voltage difference:

Example: 9.2

How much the density of the electric current is generated by the passage of an electrical current of 2 A in a 0.1 cm cross-section area of the conductor.

Solution

$$J = \frac{I}{A} = \frac{2}{0.1 \times 10^{-2}} = 2000 \ \frac{A}{m^2}$$

Example: 9.3

cross-section area of copper wire is equal to 2×10^{-6} m^2, with an electric current 8 A. If the density of the charge carriers in copper is equal to $8 \times 10^{28} \ \frac{elect}{m^3}$. Calculate the electrical current density and speed of the charge carriers inside the conductor.

Solution

Current density:

$$J = \frac{I}{A}$$

$$= \frac{8}{2 \times 10^{-6}} = 4 \times 10^{6} \quad \frac{A}{m^2}$$

Speed of the charge carriers:

$$v = \frac{J}{n\,e}$$

$$= \frac{4 \times 10^{6}}{(8 \times 10^{28}) \cdot (1.6 \times 10^{-19})} = 3.13 \times 10^{-4} \quad \frac{m}{s}$$

Then we compensate in the Law of power as follows:

$$P = \frac{V^2}{R}$$

$$= \frac{(120)^2}{8} = 1800 \text{ Watt}$$

d. Connecting resistors

Resistors can be connected in different ways to obtain large or small values compared to the original values of available resistors.

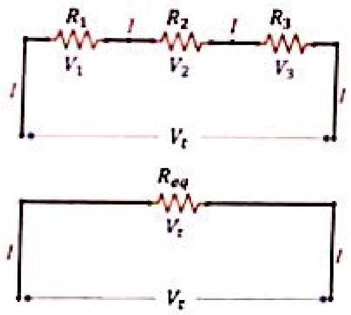


Figure 9.3: The resistors are connected in series

Connecting resistors in series

It is to connect the resistors in the form of a series, so that the end of the first resistor is with the beginning of the second resistor and so on as described in the Figure (9.3)

The characteristics of this type of connection include:

1. The electrical current is equal in the circuit.
2. The total voltage difference is distributed on the resistors.

In order to calculate the equivalent resistance collected for a set of series resistors, as shown in Figure (9.3). Note that the total voltage difference equals the voltage difference on the resistors:

$$V_t = V_1 + V_2 + V_3$$

Since the electric current I passing in all resistances is the same:

$$V_1 = V_2 = V_3 = V$$

Compensation for the current of the Ohm Law:

$$\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad (9.8)$$

Example: 9.8

Three resistances amounting to 18 Ω, 12 Ω, 6 Ω connected in parrlel, how much of the equivalent resistance?

Solution

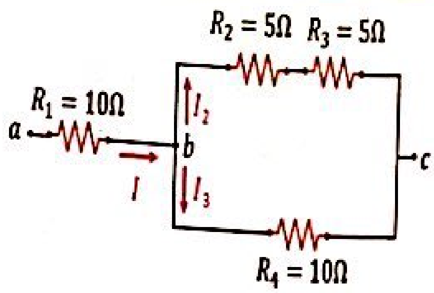
$$\frac{1}{R_{equ}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$= \frac{1}{18} + \frac{1}{12} + \frac{1}{6} = \frac{11}{36}$$

$R_{equ} = 3.3\ \Omega$

Example: 9.9

Four resistant conducting as in the Figure.



a. Find the equivalent resistance between the points a and c?

b. How much of the current in each resistance if a total voltage difference of 15 V is applied between points a and c?

Exercises

1. A battery with a charge of 40 Ah, fueling an electrical load with a current of (0.5A). How long does it take for the battery to exhaust its charge?

2. If the specific resistance to iron $\rho = 10 \times 10^{-8} \Omega m$, how much is the iron conductivity?

3. A mass of silver length $10 cm$ placed between the two ends of the voltage difference equal to 20V; find the strength of the electric field and the density of the current if the specific resistance of silver $\rho = 1.59 \times 10^{-8} \Omega m$.

4. A copper wire, cut by a circular radius $1 mm$, with an electric current equal to 4A. How much current density is and how fast are electrons if the density of electrons is in copper ($n_{cu} = 8.5 \times 10^{28}/m^3$)

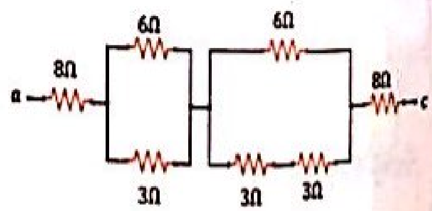
5. 480 Ω resistant light bulb when operated from an voltage source of 240V. How much electrical power is consumed in the lamp?

6. Electric oven with power 1800W. If it is powered from a 240V voltage source, how much current is withdrawn? And how much is the resistance of the oven equal to?

7. Regular Wire resistance 50 Ω divided into five equal lengths. If the five parts connected in parallel, how much resistance is equivalent?

8. Nickel chrome wire, circular section 0.2mm radius, so if the wire resistance is 48 Ω when it is powered at a 240V voltage source, how much current is withdrawn?

9. Find the equivalent resistance between the a and c points in the corresponding shape. And calculate the current in the system if the voltage difference 42 V is applied between a and c applies?



10. If the a and c ends in the corresponding shape is connected to voltage source equal to 10V, find the current in each resistance?

$$= \frac{20}{7.96} = 2.5 \ A$$

c. power

Electrical power P is the energy or work done to transfer electrical charges in a conductor per unit time.

$$P = \frac{W}{\Delta t} = \frac{Q\,V}{\Delta t} = I\,V$$

That is, the electrical power is equal to the product of the voltage difference by the intensity of the electrical current passing through the conductor. With compensation from Ohm's Law we obtain:

$$P = V\,I \quad or \quad P = R\,I^2 \quad or \quad P = \frac{V^2}{R} \qquad (9.6)$$

The electrical power is measured in units of watt, as:

$$1\ watt = \frac{1\,J}{1\ sec}$$

Example: 9.6

nickel chrome heater has an 8 Ω resistant, works on a 120 V voltage. Find the current and electrical power that passes through the heater wire.

Solution

We find the strength of the current first:

$$I = \frac{V}{R}$$

$$= \frac{120}{8} = 15\ A$$

Chapter 10 :

Light

1. Nature of Light
2. Reflection
3. Refractive

This section begins by introducing the nature of light, and then study the phenomenon of geometric optics such as the reflection of rays from the surfaces and their refraction when light crosses the boundaries between different media.

1. Nature of Light

In the past, light was considered a torrent of small particles emitted from visible objects or from the eye of the beholder. Newton was the main designer of the particle nature model of light, considering that light is a particle emitted from the light source. Newton used this idea and explained the phenomena of reflection and refraction, and most scientists of his time accepted this particulate model. But despite this acceptance, another model was proposed during Newton's lifetime, considering that light is a kind of wave movement.

German physicist Huygens lives btween 1629-1695

In 1678, the German physicist Huygens showed that the waveform of light could also explain the phenomena of reflection and refraction. In 1801, young was able to explain the phenomenon of interference by the waveform of light. The discovery of the phenomena of diffraction and polarization in the 19th century led to the general acceptance of the waveform, where Newton's particulate model was unable to explain any of these phenomena. In 1887 Hertz experimentally generated electromagnetic waves.

Although traditional electromagnetic theory, as well as classical mechanics, was able to explain most natural phenomena until the early 20th century, they could not explain some phenomena, Such as the phenomenon of black body radiation and the phenomenon of photoelectric effect. In 1905, Einstein proposed an explanation of the phenomenon of photoelectric effect using a model based on quantum hypothesis developed by Max Plank in 1900, and Einstein angle of 180° and back to its source when the angle between the mirrors 90°) is known as the phenomenon of Retro reflection. And it has many applications and when a third vertical mirror is placed on the first two.

This phenomenon was used in rear car lamps to reflect the light falling on it to its source. It is also used in traffic signs as a sign (stop) and in the shoes and clothes of athletes to be seen in the dark.

It should be noted that the general law of the total deviation angle of a beam reflected respectively from two flat mirrors between them an angle (Φ) equal to $(360 - 2\Phi)$.

3. Refractive

When light ray's incident on a boundary line between two different mediums in terms of light density, part of the light intensity is reflected and the rest is refracted as shown in Figure (10.5). Refraction is also governed by two laws:

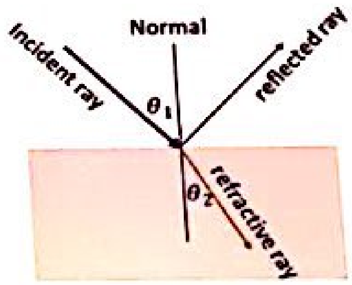


Figure 10.5: Refraction of light inside a transparent medium.

1. The incident ray, the reflected ray, the refracted ray and the normal lie in the same plane.
2. The refracted beam changes its direction and is launched at an angle θ_2 called the refractive angle depending on the characteristics of the two mediums and the angle of the incident θ_1 according to the relationship:

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} \qquad (10.2)$$

Where v_1 is the speed of light in the first medium and v_2 is the speed of light in the second medium. It is worth noting that the

Solution

a. Equivalent resistance:

Resistance (R_{23}) equivalent to R_3 and R_2 is equal to

$$R_{23} = R_2 + R_3$$
$$= 5\Omega + 5\Omega = 10\Omega$$

Resistance (R_{234}) equivalent to R_4 and R_3 and R_2 is equal to

$$\frac{1}{R_{234}} = \frac{1}{R_{23}} + \frac{1}{R_4}$$
$$= \frac{1}{10} + \frac{1}{10} = \frac{1+1}{10} = \frac{2}{10}$$

$$R_{234} = 5\Omega$$

Resistance (R_{ac}) equivalent to R_4 and R_3 and R_2 and R_1 between the two points a and c

$$R_{ac} = R_1 + R_{234}$$
$$= 10 + 5 = 15\Omega$$

b. Total current I in the resistance system:

$$I = \frac{V}{R}$$
$$= \frac{15V}{15\Omega} = 1A$$

So, the total current is equal to 1A. At point b, this current is divided into two equal parts I_2 and I_3, each with a magnitude of 0.5A, because the two branches have equal resistance. The current passing in the R_2, R_3 and R_4 resistors is equal to 0.5A, while the current passing in R_1 resistance is equal to 1A.

as in Figure (10.2). The phenomenon of reflection is governed by two basic laws:

1. The direction of the reflected ray is at the same plane as the incident ray and perpendicular to the reflected surface.
2. The angle at which the ray incident on the surface is equal to the angle at which it is reflected.

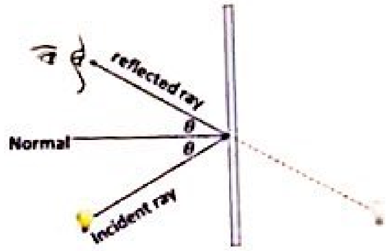


Figure 10.3: the incident ray angle is equal to the of reflection angle.

If the incident ray and the reflected ray make the angles of the θ_1 and the θ_2 with the normal on the surface respectively, as in Figure (10.3). A normal is a line that draws at the same plane as the incident ray and the reflected ray at their meeting point on the reflecting surface. The second law of reflection can be drafted as follows:

$$\theta_1 = \theta_2 \quad (10.1)$$

The reflection of light from the flat surfaces is called a regular reflection, such as the reflection from the surface of the flat mirror as in Figure (10.3), but if the surface is irregular so that the roughness on its surface is greater than the wavelength of the incident light rays, the images of the object do not appear as a result of the reflection of light from the rough surfaces. The reflection of light from the bathroom mirror is a regular reflection, while the reflection of light from the surface of the book sheet is an irregular reflection.

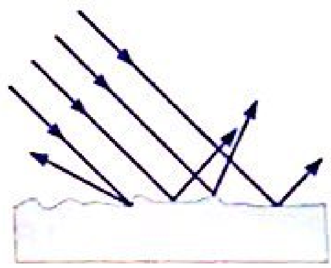
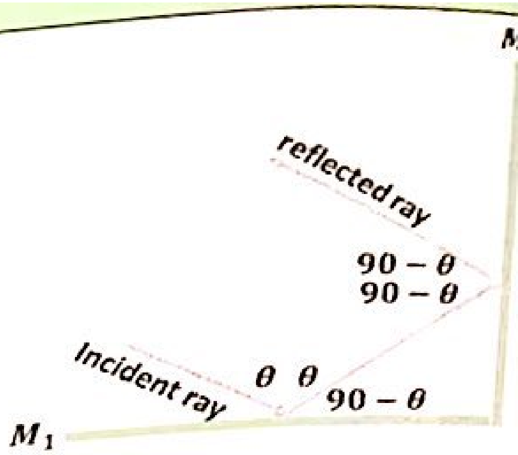


Figure 10.4: reflected light from a rough surface.

Example: 10.1

Two flat mirrors that create a right angle, as shown in the Figure. The incident ray on the first mirror M_1 is at an angle θ from the normal .



1. Find the direction of the reflected ray from the second mirror M_2 .
2. Calculate the total deviation angle .

Solution

From the Figure we find that the incident ray reflects from the first mirror and goes to the second mirror and falls on it and then reflects from it as well.

From the law of reflection, the first reflected ray creates an angle θ with the normal as well, so we find that the angle of deviation of the beam after the first reflection (reflection of M_1) is equal to $180 - 2\theta$

Since the angle of fall on M_2 is equal to $(90 - \theta)$ by exchange, the reflection angle of M_2 is equal to $(90 - \theta)$.

So, the angle of deviation of the beam after the second reflection (reflection from M_2) is equal to

$$180 - 2(90 - \theta)$$

So, the total deviation angle is equal to

$$180 - 2\theta + 180 - 2 \times 90 + 2\theta = 180^o$$

For example (10.1), we conclude that the incident ray reverses its direction if it falls at an angle on two perpendicular flat mirrors. This phenomenon (the deviation of the beam at an

Where n is the refractive index in the medium in which the wavelength is λ_n and the wavelength in the vacuum is equal to the λ

Example: 10.2

A light ray incident from the air on the water at an angle of 30° with normal. Part of the incident ray was reflected and another part was refracted into the water, as the water refraction index (1.33).

1. Find the reflection angle.
2. Find the refractive angle.

Solution

1. Since the reflection angle is equal to the incident angle, then the reflection angle is equal to 30°.

2. We apply the Snell law.

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$

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

$$= \frac{1}{1.33} \sin(30) = 0.375$$

$$\theta_2 = \sin^{-1}(0.375) = 22^o$$

Example: 10.3

A 589 nm wavelength beam travels through the air, falling on a flat surface of the glass panel at a 30° fall angle with the vertical, where the glass refractive index (n=1.52).

1. Find the refractive angle.
2. Find the speed of light in the glass.
3. How long is the wavelength in the glass?

considered light made up of particles named photons with specific amounts of energy

In light of the developments of modern physics, we have to consider that light is of a dual nature. It sometimes shows wave characteristics and particle properties at other times.

Light rays

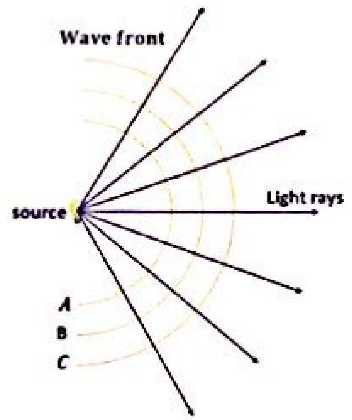


Figure 10.1: The light rays.

Light rays are used in the study of light flow. Light rays show light moving in a straight-line direction as it passes through a unified medium of light properties. To understand the wave approximation, we must note that the rays of any wave are straight lines indicating the direction of the wave's flow, and fall vertically on the wave front as shown in Figure (10.1). The wave front is a point in the middle where the wave disturbance has the same phase (such as waves of the surface of the water in the static pond when a stone is thrown). wave approximation is used in the study of mirrors and lenses and in the design of optical instruments such as binoculars, cameras and eyeglasses.

2. Reflection

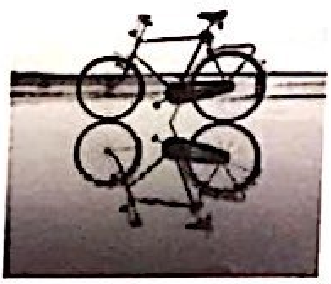


Figure 10.2: reflection bicycle picture on water surface.

Reflection is a change in the direction of the wave's front when it falls on a reflective surface so that the wave's front bounces back from the reflecting surface, such as the reflection of water waves at the edge of the stalactite, and the reflection of waves along a tendon or rope at the edge of the fixation. The reflection of sound waves also causes the phenomenon of echo and the reflection of light waves from the surface of the water

Solution

1. Since $\theta_2 \langle \theta_1$ because the speed of light in glass is smaller than its speed in the air. In this Example, we apply the refraction law only after we rearrange the Snell law to find θ_2

$$\theta_2 = sin^{-1}(\frac{n_1}{n_2} sin\, \theta_1)$$

$$= sin^{-1}(\frac{1}{1.52} sin\, 30^o) = 19.2^o$$

2. Speed of light in glass:

$$v = \frac{c}{n}$$

$$= \frac{3.00 \times 10^8 ms^{-1}}{1.52} = 1.97 \times 10^8 ms^{-1}$$

3. wavelength of this ray in the glass.

$$\lambda_n = \frac{\lambda}{n}$$

$$= \frac{589nm}{1.52} = 388nm$$

Example: 10.4

A green light ray with wavelength in the vacuum ($5 \times 10^{-7} m$) entered a glass panel of the refraction index ($n = 1.5$).

1. What is the speed of light in the glass?
2. What is the wavelength of light in the glass?

Solution

1. The speed of light in the glass:

$$n = \frac{c}{v}$$

Where c the speed of light in the vacuum and v the speed of light in the middle concerned. n is a relative number larger than one because c is always greater than v.

When the light moves from one medium to another, its frequency does not change because the energy of the incident ray does not change from that of the refracted ray, but the length of its wave λ. Given the Figure (10.7) we find that the incident ray from the first medium has the same frequency as the refracted ray in the second medium. If we code the light frequency with the symbol f, we find that:

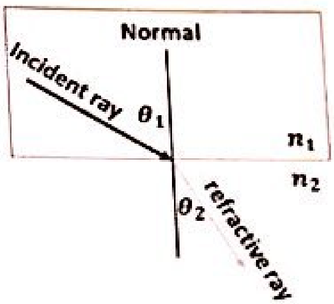


Figure 10.7: Refraction of light in different mediums

$$v_1 = \lambda_1 f$$

$$v_2 = \lambda_2 f$$

And since $v_1 \neq v_2$ so $\lambda_1 \neq \lambda_2$, we can find the relationship between the refractive index and the wavelengths.

$$\frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{\frac{c}{n_1}}{\frac{c}{n_2}} = \frac{n_2}{n_1}$$

Compensation in the equation (10.2) we find that:

$$n_1 sin\theta_1 = n_2 sin\theta_2 \qquad (10.3)$$

This law is known as the Snell law. We can also conclude:

$$n_1\lambda_1 = n_2\lambda_2$$

So, if the first medium is the vacuum ($n_1 = 1$), we come to the equation:

$$n = \frac{\lambda}{\lambda_n}$$

path of the beam of light through the two mediums is reversible. We can also add that the light when moving from the medium of its velocity is greater to the medium of its velocity less as in Figure (10.6), the refractive angle of the ray in glass θ_2 is less than the angle of incident of the ray from the air θ_1 and the ray refracted close to the vertical. When it moves from the medium of its velocity less to the medium of its velocity greater as in the Figure (10.6), the refractive angle of the rat out into the air θ_4 is greater than the angle of incident into the glass θ_3 and the ray refracted away from the normal.

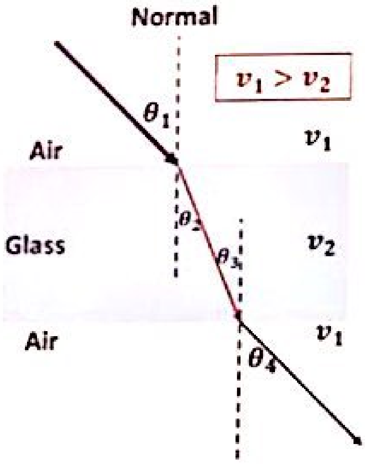


Figure 10.6: The light refracted into the glass and then exits to the space

The behaviour of light when it moves from air, for example, to another medium and then going out into the air again is a source of confusion for students. The light goes in the air at a speed of $3 \times 10^8 \frac{m}{s}$, but slows down to $2 \times 10^8 \frac{m}{s}$ when it enters a refracted of glass. When it comes out into the air again, its velocity jumps to $3 \times 10^8 \frac{m}{s}$. This behavior is very different from the behavior of particles in the media. For example, if a shot is fired through multiple circles, it never increases after it is reduced within different circles, but it continues to decrease until it is exhausted.

Refractive index (n)

In general, the speed of light in any medium is less than its speed in the vacuum. It is appropriate to define the Refraction index for any medium using the following ratio:

$$n = \frac{c}{v}$$

Total Internal Reflection

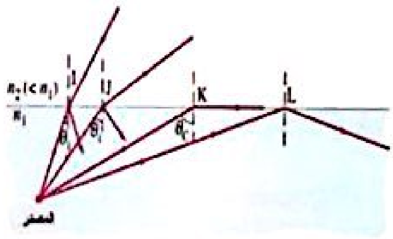


Figure 10.10: Total internal refraction.

When light incident from the medium of a larger refraction index to another less refractive index, the light refraction away from the normal. The refraction angle is greater than the incident angle. When the refractive angle is 90°, the ray refracts parallel to the surface separating the two mediums as in Figure (10.10). The incident angle in this case is called critical angle θ_c, where:

$$sin\theta_c = \frac{n_2}{n_1} \quad (10.4)$$

All the ray's incident at an angle greater than the critical angle are reflected entirely internally in what is known as total internal reflection.

Example: 10.5

Find the critical angle for a light ray move from the glass to the air, where the glass refraction index is n=1.5.

Solution

$$sin(\theta_c) = \frac{n_2}{n_1}$$

$$\theta_c = sin^{-1}(\frac{n_2}{n_1})$$

$$= sin^{-1}(\frac{1}{1.5}) = 42^o$$

Dispersion

A very important characteristic of the refractive index (n) for each medium is that the refractive index changes with the wavelength of the light ray that passes through the medium. This property results in dispersion. Since (n) depends on the wavelength, the Snell refractive law confirms that light with different wavelengths refractive at different angles.

The red wavelength refraction index is smaller than the violet wavelength refraction index. This shows that the refractive index decreases as the wavelength increases. If we assume that a white light pack (a mixture of all visible colours) fell on a prism as in Figure (10.8). The angle of dispersion depends on the wavelength, i.e. each wavelength refractives at a different angle. The rays coming out of the prism are also arranged by colour as follows (red, orange, yellow, green, blue and violet), in what is known as the visible spectrum.

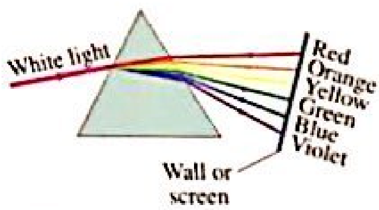


Figure 10.8: Light dispersion during prism

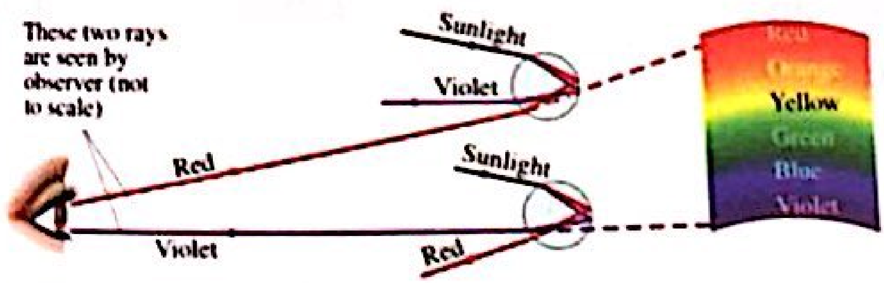


Figure 10.9: The visible spectrum.

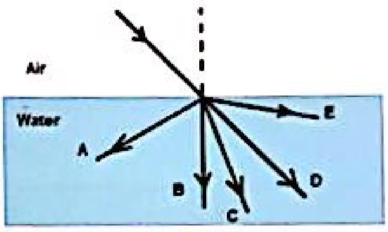
The dispersion of light in a visible spectrum is often seen in nature in what is known as the Rainbow, which is usually seen by the viewer when it is placed between the sun and the place of rain and looks in the direction of the latter as in Figure (10.9)

Exercises

1. A monochromatic light source that emits a wavelength in the air λ=495 nm. When the light passes through a liquid, its wavelength is decrease to 434nm. What is the refraction index of that fluid?

2. What happens to the light wave when it travels from air to glass?
   a. The speed remains constant.
   b. Speed increases.
   c. Wavelength increases.
   d. Wavelength remains constant.
   e. frequency remains constant.

3. Light goes from air to water, some possible paths of light beam in water as in Figure. What paths is taken by the light beam?



4. The wavelength of the helium-neon laser beam equals 632.8nm in the air. How much is the frequency?

5. If the wavelength of the helium-neon laser beam is equal to 632.8nm in the air. How long is the wavelength in the glass if the light refraction index in the glass is equal to 1.5?

6. Find the speed of light in the glass, if you know that the light refraction index in the glass is n=1.66.

7. Find the speed of light in the water, if you know that the light refraction index in water is n=1.333.

Units and dimensions of some physical quantities

Quantity	Dimension	Units	
Distance	$[L]$	m	meter
Time	$[T]$	s	second
Mass	$[M]$	kg	kilogram
Velocity	$[LT^{-1}]$	m/s	-
Acceleration	$[LT^{-2}]$	m/s^2	-
Force	$[MLT^{-2}]$	$kg.m/s^2$	newton
Stress/Pressure	$[ML^{-1}T^{-2}]$	$kg/m.s^2$	pascal
Density	$[ML^{-3}]$	kg/m^3	-
Energy/Work	$[ML^2T^{-2}]$	$kg.m^2/s^2$	joule
Power	$[ML^2T^{-3}]$	$kg.m^2/s^3$	watt

$$v = \frac{c}{n}$$

$$= \frac{3 \times 10^8}{1.5} = 2 \times 10^8 ms^{-1}$$

2. The wavelength of this beam in the glass:

$$n = \frac{\lambda}{\lambda_n}$$

$$\lambda_n = \frac{\lambda}{n}$$

$$= \frac{5 \times 10^{-7}}{1.5} = 3.33 \times 10^{-7} m$$

The Higgins Principle

The laws of reflection and refraction were mentioned without proof, they were developed using geometric methods suggested by Higgins. Higgins' principle is to develop a geometric method for using the front the wave to locate subsequent waves. All points on the wave's front are a source for the production of secondary spherical waves that travel in the medium with the same characteristics as the source wave.

The Higgins principle may not seem important now because predicting future wave release sites may not be useful, but later in the study of interference, wave release sites are essential to determine the constructive interference of destructive interference.

Appendix

Units of Measurement of some physical quantities

Length

	m	cm	km	in.	ft
1 meter	1	10^2	10^{-3}	39.37	3.281
1 centimeter	10^{-2}	1	10^{-5}	0.393 7	3.281×10^{-2}
1 kilometer	10^3	10^5	1	3.937×10^4	3.281×10^3
1 inch	2.540×10^{-2}	2.540	2.540×10^{-5}	1	8.333×10^{-2}
1 foot	0.304 8	30.48	3.048×10^{-4}	12	1
1 mile	1 609	1.609×10^5	1.609	6.336×10^4	5 280

Mass

	kg	g	slug	u
1 kilogram	1	10^3	6.852×10^{-2}	6.024×10^{26}
1 gram	10^{-3}	1	6.852×10^{-5}	6.024×10^{23}
1 slug	14.59	1.459×10^4	1	8.789×10^{27}
1 atomic mass unit	1.660×10^{-27}	1.660×10^{-24}	1.137×10^{-28}	1

Note: 1 metric ton = 1 000 kg.

Time

	s	min	h	day	yr
1 second	1	1.667×10^{-2}	2.778×10^{-4}	1.157×10^{-5}	3.169×10^{-8}
1 minute	60	1	1.667×10^{-2}	6.994×10^{-4}	1.901×10^{-6}
1 hour	3 600	60	1	4.167×10^{-2}	1.141×10^{-4}
1 day	8.640×10^4	1 440	24	1	2.738×10^{-5}
1 year	3.156×10^7	5.259×10^5	8.766×10^3	365.2	1

Speed

	m/s	cm/s	ft/s	mi/h
1 meter per second	1	10^2	3.281	2.237
1 centimeter per second	10^{-2}	1	3.281×10^{-2}	2.237×10^{-2}
1 foot per second	0.304 8	30.48	1	0.681 8
1 mile per hour	0.447 0	44.70	1.467	1

Note: 1 mi/min = 60 mi/h = 88 ft/s.

Force

	N	lb
1 newton	1	0.224 8
1 pound	4.448	1

Energy, Energy Transfer

	J	ft · lb	eV
1 joule	1	0.737 6	6.242×10^{18}
1 foot-pound	1.356	1	8.464×10^{18}
1 electron volt	1.602×10^{-19}	1.182×10^{-19}	1
1 calorie	4.186	3.087	2.613×10^{19}
1 British thermal unit	1.055×10^{3}	7.779×10^{2}	6.585×10^{21}
1 kilowatt-hour	3.600×10^{6}	2.655×10^{6}	2.247×10^{25}

	cal	Btu	kWh
1 joule	0.238 9	9.481×10^{-4}	2.778×10^{-7}
1 foot-pound	0.323 9	1.285×10^{-3}	3.766×10^{-7}
1 electron volt	3.827×10^{-20}	1.519×10^{-22}	4.450×10^{-26}
1 calorie	1	3.968×10^{-3}	1.163×10^{-6}
1 British thermal unit	2.520×10^{2}	1	2.930×10^{-4}
1 kilowatt-hour	8.601×10^{5}	3.413×10^{2}	1

Pressure

	Pa	atm
1 pascal	1	9.869×10^{-6}
1 atmosphere	1.013×10^{5}	1
1 centimeter mercury[a]	1.333×10^{3}	1.316×10^{-2}
1 pound per square inch	6.895×10^{3}	6.805×10^{-2}
1 pound per square foot	47.88	4.725×10^{-4}

	cm Hg	lb/in.^{2}	lb/ft^2
1 pascal	7.501×10^{-4}	1.450×10^{-4}	2.089×10^{-2}
1 atmosphere	76	14.70	2.116×10^{3}
1 centimeter mercury[a]	1	0.194 3	27.85
1 pound per square inch	5.171	1	144
1 pound per square foot	3.591×10^{-2}	6.944×10^{-3}	1

[a]At 0°C and at a location where the free-fall acceleration has its "standard" value, 9.806 65 m/s^2.

14. The Cambridge Handbook of Physics Formulas, Graham Woan, Cambridge university press, UK, 2000.

8. A beam of light moved from the air to another medium at an incident angle of θ_1=45°. Find a refractive angle θ_2, if you know that the light refraction index in this medium is n=1.458.

9. How much angle of deviation in the direction of a light beam that incident at an angle on a flat mirror, reflecting on it to incident on another flat mirror, and the angle between the two mirrors at the beam level was equal to 120°?

10. How much is the critical angle when the air-water separation of a light beam emanated from the bottom of a water tank? Note that the light refraction index in water is n=1.33.

Some physical constants

Quantity	Symbol	Value
Avogadro's number	N_A	6.022 141 99 (47) X 10^{23} particles/mol
Boltzmann's constant	k_B	1.380 650 3 (24) X 10^{-23} J/K
Coulomb constant	k_e	8.987 551 788 X 10^{9} $N \cdot m^2/C^2$
Electron mass	m_e	9.109 381 88 (72) X 10^{-31} kg
Proton mass	m_p	1.672 621 58 (13) X 10^{-27} kg
Elementary charge	e	1.602 176 462 (63) X 10^{-19} C
Gas constant	R	8.314 472 (15) J/K · mol
Gravitational constant	G	6.673 (10) X 10^{-11} $N \cdot m^2/kg^2$
Neutron mass	m_n	1.674 927 16 (13) X 10^{-27} kg
Permeability of free space	μ_0	4π X 10^{-7} T · m/A
Permittivity of free space	ϵ_0	8.854 187 817 X 10^{-12} $C^2/N \cdot m^2$
Planck's constant	h	6.626 068 76 (52) X 10^{-34} J · s
Speed of light in vacuum	c	2.997 924 58 X 10^{8} m/s
Gravitational acceleration	g	9.807 m/s^2
Thermomechanical equivalent	J	4.1855 J/cal
Standard atmospheric pressure		1.0132×10^5 N/m^2

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