# The Forces

## Exercise Solutions

**Question 1:** The gravitational force acting on a particle of 1g due to a similar particle is equal to $6.67 \times 10^{-17}$ N. Calculate the separation between the particles.

**Solution:**
Mass of the particle, m = 1 g or 1/1000 kg

Let the r be the distance between the particles, then the gravitational force between the particles,
$F = 6.67 \times 10^{-17}$ N

Now, gravitational force existing between the particles:

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

$$6.67 \times 10^{-17} = 6.67 \times 10^{-11} \times \left(\frac{\frac{1}{1000} \times \frac{1}{1000}}{r^2}\right)$$

$$\Rightarrow r^2 = 6.67 \times 10^{-11} \times \frac{10^{-6}}{6.67 \times 10^{-17}}$$

=> r = 1m

Separation between the particles is 1 m.

**Question 2:** Calculate the force with which you attract the earth.

**Solution:**
Let m be the mass of the man standing on earth, the earth's gravitational force will act on man mg.

Where m = mass of the man and g = acceleration due to gravity on the surface of earth =10 $m/s^2$

Let mass of the man=50 kg.
F = W = mg = 50x10 = 500N = force acting on the man.
Man is also attracting the earth with a force of 500 N.

**Question 3:** At what distance should two charges, each equal to 1 C, be placed so that the force between them equals your weight?

**Solution:**

Coulomb's force of attraction between two charges is given by –

$$F = k\,\frac{q_1 \times q_2}{r^2}$$

Where, $q_1$ and $q_2$ are the charges, r= distance between the charges and k = proportionality constant

Here $q_1 = q_2 = 1C$ and $k = 9 \times 10^9$

=> $F = k/r^2$ ...(1)

Force of attraction is equal to the weight (Given)
$F = mg$ ...(2)

Equation (1) and (2), we have

$mg = k/r^2$ ...(3)

Let us assume that, mass = m = 64 kg

(3)=> $r = (3x10^4)/\sqrt{64}$

r = 3750 m

**Question 4:** Two spherical bodies, each of mass 50 kg, are placed at a separation of 20 cm. Equal charges are placed on the bodies and it is found that the force of Coulomb repulsion equals the gravitational attraction in magnitude. Find the magnitude of the charge placed on either body.

**Solution:**
Given, mass = 50 kg, r = 20 cm or 0.2 m

Coulomb's force of repulsion between two charges:

$$F_c = k\,\frac{q_1 \times q_2}{r^2}$$

Where, $q_1$ and $q_2$ are the charges, r= distance between the charges and k = proportionality constant

Here $q_1 = q_2 = 1C$ and $k = 9 \times 10^9$

Again, gravitational force,

$$F_G = G \times \frac{m_1 \times m_2}{r^2}$$

Where, G = universal gravitation constant

$m_1$ = mass of first object and $m_2$ = mass of second object and r = distance between the objects

$m_1 = m_2$ = 50Kg

Now,

$F_G = F_C$

=>

$$G \times \frac{m_1 \times m_2}{r^2} = k\ \frac{q \times q}{r^2}$$

By putting the values, we have

$$6.67\ \times\ 10^{-11} \times \frac{50 \times 50}{0.2^2} = 9 \times 10^9\ \frac{q \times q}{0.2^2}$$

$$\Rightarrow q =\ 4.3 \times 10^{-9}\ C$$

**Question 5:** A monkey is sitting on a tree limb. The limb exerts a normal force of 48 N and a frictional force of 20 N. Find the magnitude of the total force exerted by the limb on the monkey.

**Solution:**
Given: Normal force = 48N and Frictional force = 20N

The resultant magnitude of the force, say R,

$R^2 = (48)^2 + (20)^2$

or R = 52 N

**Question 6:** A body builder exerts a force of 150 N against a bullworker and compresses it by 20 cm. Calculate the spring constant of the spring in the bullworker.

**Solution:**

Body builder exerts a force = 150N
Compressed length = 20cm or 0.2m

Force applied on a string: F = kx
Where, K = spring constant and x = displacement

150 = k x 0.2

=> k = 750 N/m

**Question 7:** A satellite is projected vertically upwards from an earth station. At what height above the earth's surface will the force on the satellite due to the earth be reduced to half its value at the earth station? (Radius of the earth is 6400 km)

**Solution:**
Given, radius of Earth = 6400 Km

Let R be the radius of earth, M be the mass of earth and m be the mass of the satellite.

Also assume, at height h, the force on the satellite due to earth is reduce to half.

$$F = \frac{GMm}{(R+h)^2} = \frac{GMm}{2R^2}$$

$$\Rightarrow 2R^2 = (R+h)^2 \Rightarrow R^2 - h^2 - 2Rh = 0$$

$$\Rightarrow h^2 + 2Rh - R^2 = 0$$

$$H = \frac{\left(-2R \pm \sqrt{4R^2 + 4R^2}\right)}{2} = \frac{-2R \pm 2\sqrt{2R}}{2}$$

$$= -R \pm \sqrt{2R} = R\left(\sqrt{2} - 1\right)$$

= 6400 x 0.414

= 2650 km

**Question 8:** Two charged particles placed at a separation of 20 cm exert 20 N of Coulomb force on each other. What will be the force if the separation is increased to 25 cm?

**Solution:**
Coulomb's force between two charges:

$$F_c = k\,\frac{q_1 \times q_2}{r^2}$$

Where, $q_1$ and $q_2$ are the charges, r= distance between the charges and k = proportionality constant

and $k = 9 \times 10^9$

When, r = 20 cm = 0.2m, Coulomb's force = 20 N

$$F_1 = 20 = k\,\frac{q_1 \times q_2}{0.2^2}$$

When r = 25 cm

$$F_2 = k\,\frac{q_1 \times q_2}{0.25^2}$$

Now, ratio of $F_1$ and $F_2$

$F_1/F_2 = 20/F_2 = (0.2)^2/(0.25)^2$

=> $F_2$ = 13 N (approx)

**Question 9**: The force with which the earth attracts an object is called the weight of the object. Calculate the weight of the moon from the following data: The universal constant of gravitation G = $6.67 \times 10^{-11}$ N–m$^2$/kg$^2$, mass of the moon = $7.36 \times 10^{22}$ kg, mass of the earth = $6 \times 10^{24}$ kg and the distance between the earth and the moon = $3.8 \times 10^5$ km.

**Solution:**
mass of the moon = $7.36 \times 10^{22}$ kg

mass of the earth = $6 \times 10^{24}$ kg

distance between moon and earth =$3.8 \times 10^5$ km

The force between moon and earth:

$$F_G = G \times \frac{m_1 \times m_2}{r^2}$$

$$F_G = 6.67 \times 10^{-11} \times \frac{7.36 \times 10^{22} \times 6 \times 10^{24}}{(3.8 \times 105)^2}$$

$$= 2 \times 10^{20}\, N$$

Weight of the moon is $2.0 \times 10^{20}$ N.

**Question 10:** Find the ratio of the magnitude of the electric force to the gravitational force acting between two protons.

**Solution:**
Coulomb's force of repulsion between two protons

$$F_c = k\,\frac{q_1 \times q_2}{r^2}$$

and gravitational force

$$F_G = G \times \frac{m_1 \times m_2}{r^2}$$

$G = 6.67 \times 10^{-11}$
$m_1 = m_2 = 1.67 \times 10^{-27}$

Coulomb force of repulsion between the two protons

$$F_c = 9 \times 10^9 \times \frac{(1.6 \times 10^{-19})^2}{r^2}$$

Ratio of the magnitude of the electric force to the gravitational force acting between two protons:

$$\frac{F_c}{F_G} = \frac{9 \times 10^9 \times \frac{(1.6 \times 10^{-19})^2}{r^2}}{6.67 \times 10^{-11} \times \frac{(1.67 \times 10^{-27})^2}{r^2}}$$

$$= 1.24 \times 10^{36}$$

**Question 11:** The average separation between the proton and the electron in a hydrogen atom in ground state is $5.3 \times 10^{-11}$ m. (a) Calculate the Coulomb force between them at this separation. (b) When the atom goes into its first excited state the average separation between the proton and the electron increases to four times its value in the ground state. What is the Coulomb force in this state?

**Solution:**

The average separation between the proton and the electron of a Hydrogen atom in ground state, r = $5.3 \times 10^{-11}$ m

(a) Coulomb's force of between electron and proton

$$F_c = k\,\frac{q_1 \times q_2}{r^2}$$

Where, $q_1$ and $q_2$ are the charges, r= distance between the charges and k = proportionality constant

and k = $9 \times 10^9$

$$F_c = 9 \times 10^9 \times \frac{(1.6 \times 10^{-19})}{(5.3 \times 10^{-11})^2}$$

$$= 8.2 \times 10^{-8}\,N,$$

(b) the Coulomb force when the average separation between the proton and the electron increases to four times its value in the ground state:

$$F_c = 9 \times 10^9 \times \frac{(1.6 \times 10^{-19})}{(4 \times 5.3 \times 10^{-11})^2}$$

$$= 5.1 \times 10^{-9}\,N$$

**Question 12:** The geostationary orbit of the earth is at a distance of about 36000 km from the earth's surface. Find the weight of a 120-kg equipment placed in a geostationary satellite. The radius of the earth is 6400 km.

**Solution:**
The radius of the earth = 6400 km.

Equipment weight = 120-kg

Also given, geostationary orbit of the earth is at a distance of about 36000 km from the earth's surface.

The value acceleration due to gravity above the surface of the Earth

$$g' = G \times \frac{m}{(R+h)^2}$$

$$g' = G \times \frac{m}{(36000 + 6400)^2}$$

acceleration due to gravity is 9.8 m/s$^2$

$$g = G \times \frac{m}{(6400)^2}$$

$$9.8 = G \times \frac{m}{(6400)^2}$$

Now, ratio:

$$\frac{g'}{g} = \frac{G \times \frac{m}{(36000+6400)^2}}{G \times \frac{m}{(6400)^2}}$$