Chapter 3: Forces

Dynamics: the study of why objects move as they do.

A force is a push or pull that acts on an object.

- Forces can move an object.
- Forces can stop a moving object.
- Forces can change the shape of an object.

Types of Forces

1) Contact forces: forces that touch an object

a) Tension b) Friction c) Elastic

2) Action-at-a-distance Forces (no contact)

a) Gravitational b) Electrostatic c) Magnetic

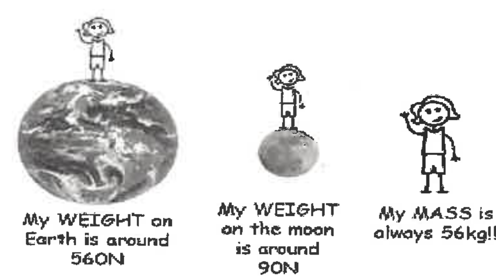
3.1 Force of Gravity

Measuring Mass

- Mass is measured in Kilograms (kg)
- 1000 grams (g) = 1 kilogram (kg)
- Mass is measured on a balance scale
- Mass does not change – it is the same everywhere in the universe

Weight (Force of Gravity)

- Amount of force on an object due to gravity
- Depends on where you are in the universe!
- Measured in newtons (N)
- 1 N is about the weight of one apple on earth



Measuring Force

- Force meters usually include a Spring or elastic that stretches or compresses.

  Ex. Spring scale

- 1 kg of mass would have a weight (force of gravity) of 9.81 N on Earth.
- To find the weight of an object on earth, you can multiply its mass by 9.81 N/kg
- This value represents the gravitational field strength, g.

$$F_g = m\,g$$

Fg = weight or force of gravity acting on an object (N)
M = mass of object (kg)
g = gravitational field strength (9.81 N/kg)

Example: What is the weight of a 8.0 kg box on earth?

$F_g = ?$
$m = 8.0\ kg$
$g = 9.81\ N/kg$

$F_g = mg$
$= (8.0\ kg)(9.81\ N/kg)$
$= 78.48\ N = 78\ N$ 2sf

Practice:

1. What force does gravity exert on a 25.0 g plum on earth?

   $m = 25.0\ g \times \frac{1\ kg}{10^3\ g} = 2.50 \times 10^{-2}\ kg$
   $g = 9.81\ N/kg$
   $F_g = ?$

   $F_g = mg$
   $= (2.50 \times 10^{-2}\ kg)(9.81\ N/kg)$
   $= 0.245\ N$ 3sf

2. Determine the mass of a gold statue, if it has a weight of 2600 N.

   $F_g = 2600\ N$
   $g = 9.81\ N/kg$
   $m = ?$

   $F_g = mg$
   $m = \frac{F_g}{g}$
   $= \frac{2600\ N}{9.81\ N/kg}$
   $= 265\ kg = 2.7 \times 10^2\ kg$ 2sf

3. The statue from question 2 is brought to the moon, where the gravitational field strength is 1.6 N/kg. How much would it now weigh?

   $m = 265\ kg$
   $g = 1.6\ N/kg$
   $F_g = ?$

   $F_g = mg$
   $= (265\ kg)(1.6\ N/kg)$
   $= 424\ N$ or $4.2 \times 10^2\ N$ 2sf

Hooke's Law (Elastic Force)

- solids have a definite shape and resists changes in shape.
- Elastic force opposes the twisting, stretching, compressing of a material.

Hooke's Law

- If a force is exerted on an object such as a spring or block of metal, the object will be stretched or compressed.
- If the stretch or compression, x, is relatively small compared to the length of the object, then x will be proportional to the force, F, placed on the object.

- the elastic force of a rubber band varies directly with the increase in length.

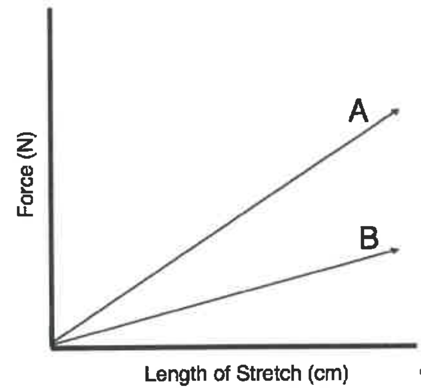
$$F_E = kx$$

F_E = elastic force (N)
k = spring constant (N/m)
x = length of stretch (m)
(or compression)

Spring constant is dependent on:

a) dimension -of object being stretched.
b) nature of the material.

Ex#1. On the adjacent graph, the stretch vs. force is plotted for two different rubber bands (A and B). Which of the two elastic bands would be thicker? How do you know?



- A would be thicker
- Requires a greater force to stretch the same amount as Elastic B

Ex#2. How long will a 5.0 cm rubber elastic band be after a 5 N weight is attached to it? (K=10.0 N/cm)?

$x = ?$

$F_E = 5N$

$K = 10.0N/cm$

$F_E = Kx$

$x = \frac{F_E}{K} = \frac{5N}{10.0N/cm}$

$= 0.5cm$

New length = 5.0cm + 0.5cm

= 5.5cm

Ex#3. What is the spring constant of a metal bar, if a 3000N force compresses it from a length of 2.55 m to a length of 2.45 m?

$x = 2.55m - 2.45m$

$= 0.10m$

$K = ?$

$F_E = 3000N$

$F_E = Kx$

$K = \frac{F_E}{x}$

$K = \frac{3000N}{0.10m}$

$= 30\,000 N/m$

Hooke's Law Problems

1. How much force would it take to stretch a steel bar with a spring constant of 2.1×10^7N/m until it was 1.00mm longer?

$F_E = ?$

$K = 2.1 \times 10^7 N/m$

$x = 1.00mm \times \frac{10^{-3}m}{1mm}$

$= 1.00 \times 10^{-3}m$

$F_E = Kx$

$= (2.1 \times 10^7 N/m)(1.00 \times 10^{-3} m)$

$= 2.1 \times 10^4 N$

2. What is the spring constant of a car spring if a 2500N force compresses it from a length of 50.0cm to a length of 40.0cm?

$K = ?$

$F_E = -2500N$

$x = 40.0cm - 50.0cm$

$= -10.0cm$

$F_E = Kx$

$K = \frac{F_E}{x}$

$K = \frac{-2500N}{-10.0cm}$

$= 250 N/cm$

or $25000 N/m$

3. a) What force would be required to compress a 20.0cm long spring to 15.0cm if the spring constant is 30.0N/m?

$x = 15.0cm - 20.0cm$
$= -5.0cm$ or $-0.050m$
$k = 30.0N/m$
$F_E = ?$

$F_E = kx$
$= (30.0N/m)(-0.050m)$
$= -1.5N$

b) What mass, when placed on top of the vertical spring, would cause the same compression?

$F_g = 1.5N$
$g = 9.81N/kg$
$m = ?$

$F_g = mg$
$m = \frac{F_g}{g} = \frac{1.5N}{9.81N/kg} = 0.153kg$
$= 0.15kg$ 2 s.f.

4. A spring is compressed 10m when a force of 5N is applied. How far does it compress when 10N is applied?

$x = 10m$
$F = 5N$
$k = ?$

$k = \frac{F}{x} = \frac{5N}{10m} = 0.5N/m$

$F = 10N$
$k = 0.5N/m$
$x = ?$

$x = \frac{F}{k} = \frac{10N}{0.5N/m} = 20m$

5. Peter is out hunting for a rabbit with his spring-loaded rock thrower. He pulls back on the spring with a force of 350N and it stretches 10cm. Determine the spring constant of the rock thrower.

$F = 350N$
$x = 10cm$ or $0.1m$
$k = ?$

$F = kx$
$k = \frac{F}{x} = \frac{350N}{0.1m}$
$= 3500N/m$

6. Sally is standing on Planet Johnston where the acceleration due to gravity is 18.3 m/s^2. She holds a spring (k=100.0N/m) in her hand.

a) If she puts a 1.2kg mass on the end of the spring, how far does it stretch?

$m = 1.2kg$
$g = 18.3N/kg$
$F_g = ?$

$F_g = mg$
$= (1.2kg)(18.3N/kg)$
$= 22.0N$

$F_E = 22.0N$
$k = 100.0N/m$
$x = ?$

$F_E = kx$
$x = \frac{F_E}{k} = \frac{22.0N}{100.0N/m} = 0.22m$

b) What mass would be required to stretch the spring 35 cm?

$x = 0.35m$
$k = 100.0N/m$
$F_E = ?$

$F_E = kx$
$= (100.0N/m)(0.35m)$
$= 35N$

$F_g = 35N$
$g = 18.3N/kg$
$m = ?$

$F_g = mg$
$m = \frac{F_g}{g} = \frac{35N}{18.3N/kg}$
$= 1.9kg$

Answers: 1. 2.1×10^4N 2. $2.5 \times 10^4N/m$ 3. a) 1.50N b) 0.153kg 4. 20m 5. $3.5 \times 10^3N/m$ 6.a) 0.22m, b) 1.9kg

Law of Universal Gravitation

- Every particle is attracted to every other particle in the universe.
- The force of the attraction depends on the mass of the objects and the distance between them.
- Gravity is a mutual force

  Ex. The force with which the earth pulls you down is equal to the force with which your mass pulls the earth up!

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

F_g = force of attraction between two objects (N)

m_1 = mass -of one object (kg)

m_2 = mass of second object (kg)

r = distance between centres of the two objects (m)

G = 6.67×10^{-11} Nm^2/kg^2 (Gravitational Constant)

Ex. 1: What is the force of attraction between two apples, each with a mass of 0.50 kg, held 10 cm apart?

$F_g = ?$

$m_1 = 0.50\ kg$

$m_2 = 0.50\ kg$

$r = 0.10\ m$

$G = 6.67 \times 10^{-11}\ \frac{N \cdot m^2}{kg^2}$

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

$$= \frac{(6.67 \times 10^{-11}\ \frac{N \cdot m^2}{kg^2})(0.50\ kg)(0.50\ kg)}{(0.10\ m)^2}$$

$$= 1.67 \times 10^{-9}\ N \text{ or } 2 \times 10^{-9}\ N \text{ 1 s.f.}$$

Ex.2: If M is the mass of the earth and r is the radius of the earth, rewrite the universal gravitation law to solve for g (Remember: F_g=mg)

For an object with a mass of "m",

$F_g = mg$

$m_1 = m$

$m_2 = M$ (mass of earth)

$G = G$

$r = r_e$ (radius of earth)

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

$$\cancel{m}g = \frac{G\cancel{m}M}{r^2}$$

$$g = \frac{GM}{r_e^2}$$ and $M = 5.98 \times 10^{24}\ kg$, $r_e = 6.38 \times 10^6\ m$

$$= \frac{(6.67 \times 10^{-11}\ \frac{N \cdot m^2}{kg^2})(5.98 \times 10^{24}\ kg)}{(6.38 \times 10^6\ m)^2}$$

$$= 9.80\ N/kg$$

Inverse Square Law

- The force of attraction between two objects is directly proportional to the square of the distance between their centres.

  If you double the distance, you reduce the force to 1/4 *the original amount; if you triple the distance, you reduce the force by* 1/9 *the amount.*

Ex#1: The force of gravity on a rocket 10 000 km from the centre of the Earth is 900 N. What will the force of gravity on the rocket be when it is 30 000 km from the centre of the Earth?

distance is 3x ∴ force is $\frac{1}{3^2} = \frac{1}{9}$

Force $= (\frac{1}{9})(900\text{ N}) = 100\text{ N}$

Ex#2: The force of gravity on a horse is about 4000 N at the Earth's surface. How far above the Earth's surface would the horse have to be in order to have a weight of 1000 N?

Force ↓ $\frac{1}{4} = \frac{1}{2^2}$ ∴ distance is 2x

distance above surface is equal to the radius $= 6.38\times10^6$ m above the Earth's surface

Gravitational Force Questions

1. Two students are sitting 1.50 m apart. One student has a mass of 70.0kg and the other has a mass of 52.0 kg. What is the gravitational force between them?

   $m_1 = 70.0$ kg
   $m_2 = 52.0$ kg
   $r = 1.50$ m
   $G = 6.67\times10^{-11}\text{ N}\cdot\text{m}^2/\text{kg}^2$
   $F_g = ?$

   $$F_g = \frac{Gm_1m_2}{r^2} = \frac{(6.67\times10^{-11}\text{ N}\cdot\text{m}^2/\text{kg}^2)(70.0\text{ kg})(52.0\text{ kg})}{(1.50\text{ m})^2} = 1.08\times10^{-7}\text{ N}$$

2. What gravitational force does the moon produce on the earth if the centres of the Earth and moon are 3.84×10^8 m apart and the moon has a mass of 7.35×10^{22} kg?

   $r = 3.84\times10^8$ m
   $m_1 = 5.98\times10^{24}$ kg
   $m_2 = 7.35\times10^{22}$ kg
   $G = 6.67\times10^{-11}\text{ N}\cdot\text{m}^2/\text{kg}^2$
   $F_g = ?$

   $$F_g = \frac{Gm_1m_2}{r^2} = \frac{(6.67\times10^{-11}\text{ N}\cdot\text{m}^2/\text{kg}^2)(5.98\times10^{24}\text{ kg})(7.35\times10^{22}\text{ kg})}{(3.84\times10^8\text{ m})^2} = 1.99\times10^{20}\text{ N}$$

3. Calculate the gravitational force on a 6.50×10^{2} kg spacecraft that is 4.15×10^{6} m above the surface of the earth.

$m_1 = 6.50\times10^{2}$ kg $= 650$ kg
$m_2 = 5.98\times10^{24}$ kg
$r = 6.38\times10^{6}$ m $+ 4.15\times10^{6}$ m
$= 1.053\times10^{7}$ m
$G = 6.67\times10^{-11}$ N·m²/kg²

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

$$= \frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(650\ \text{kg})(5.98\times10^{24}\ \text{kg})}{(1.053\times10^{7}\ \text{m})^2}$$

$= 2338$ N or 2.34×10^{3} N (3 s.f.)

4. The gravitational force between two objects that are 2.1×10^{-1}m apart is 3.2×10^{-6}N. If the mass of one object is 5.5×10^{1} kg, what is the mass of the other object?

$F_g = 3.2\times10^{-6}$ N
$r = 2.1\times10^{-1}$ m $= 0.21$ m
$m_1 = 55$ kg
$m_2 = ?$
$G = 6.67\times10^{-11}$ N·m²/kg²

$$F_g = \frac{G m_1 m_2}{r^2} \qquad m_2 = \frac{F_g r^2}{G m_1}$$

$$m_2 = \frac{(3.2\times10^{-6}\ \text{N})(0.21\ \text{m})^2}{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(55\ \text{kg})}$$

$= 38.47$ kg
$= 38$ kg (2 s.f.)

5. If two objects, each with a mass of 2.0×10^{2} kg, produce a gravitational force between them of 3.7×10^{-6}N, what is the distance between them?

$m_1 = 200$ kg
$m_2 = 200$ kg
$F_g = 3.7\times10^{-6}$ N
$G = 6.67\times10^{-11}$ N·m²/kg²
$r = ?$

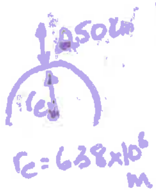
$$F_g = \frac{G m_1 m_2}{r^2} \qquad r = \sqrt{\frac{G m_1 m_2}{F_g}}$$

$$r = \sqrt{\frac{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(200\ \text{kg})(200\ \text{kg})}{3.7\times10^{-6}\ \text{N}}}$$

$= 0.85$ m (2 s.f.)

6. The weight of an astronaut on the surface of the earth is 750N.

a) What is his weight when he is at the International Space Station, 250 km above the Earth's surface?



On Earth:
$m = ?$
$F_g = 750$ N
$g = 9.81$ N/kg

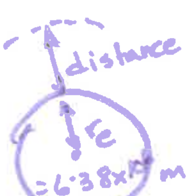
$$m = \frac{F_g}{g} = \frac{750\ \text{N}}{9.81\ \text{N/kg}} = 76.5\ \text{kg}$$

In Space:
$m_1 = 76.5$ kg
$m_2 = 5.98\times10^{24}$ kg
$r = 2.5\times10^{5}$ m $+ 6.38\times10^{6}$ m
$= 6.63\times10^{6}$ m
$G = 6.67\times10^{-11}$ N·m²/kg²

$$F_g = \frac{G m_1 m_2}{d^2} = \frac{(6.67\times10^{-11})(76.5\ \text{kg})(5.98\times10^{24}\ \text{kg})}{(6.63\times10^{6}\ \text{m})^2}$$

$= 694$ N $= 690$ N (2 sf)

b) How far above the earth's surface does he need to be before he is half his weight on earth?



$F_g = 375$ N
$m_1 = 76.5$ kg
$m_2 = 5.98\times10^{24}$ kg
$G = 6.67\times10^{-11}$ N·m²/kg²
$r = ?$

$$F_g = \frac{G m_1 m_2}{r^2} \qquad r = \sqrt{\frac{G m_1 m_2}{F_g}}$$

$$= \sqrt{\frac{(6.67\times10^{-11})(76.5\ \text{kg})(5.98\times10^{24}\ \text{kg})}{375\ \text{N}}}$$

$= 9.02\times10^{6}$ m

Distance above surface
$= 9.02\times10^{6}$ m
$- 6.38\times10^{6}$ m
$= 2.64\times10^{6}$ m

ANSWERS: 1) 1.08×10^{-7}N 2) $1,99\times10^{20}$N 3) 2.34×10^{3}N 4) 39kg 5) 0.85m 6) a) 690N b) 2.64×10^{6}m

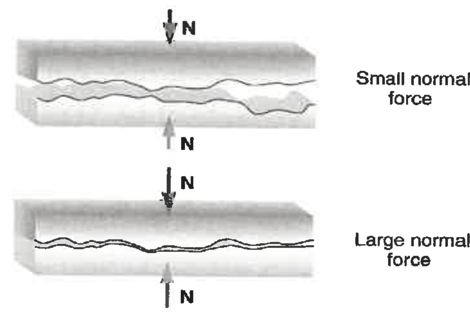
Fix 38kg

3.2 Friction

- Friction is the force that opposes motion between two surfaces in contact.
- **static friction** is the force that opposes the start of motion.
- **Kinetic friction** is the force needed to Keep an object in motion.
- Kinetic friction is always less than static friction.
- To keep an object moving at a constant speed, you must apply an equal but opposite force to the force of friction.

Sliding Friction

The force of friction, F_f, is proportional to the force applied perpendicular to the surfaces, called the normal force, F_N.



$$F_f = \mu F_N$$

μ = coefficient of friction
(constant that depends on 2 surfaces in contact)

F_N = normal force pushing 2 surfaces together, equal to W (N)

F_f = Force of friction (N)

F_f is dependent on:
a) smoothness of the surface
b) mass of the object

F_f is independent of:
a) size of the area in contact
b) size of the object.

Ex#1. The coefficient of friction between 2 materials is 0.35. A 5.0 kg object is being pulled at a constant rate.

a) What is the normal force acting on the object?

$m = 5.0 kg$
$g = 9.81 N/kg$
$F_g = ?$

$F_g = mg$
$= (5.0 kg)(9.81 N/kg)$
$= 4.9 N$

$F_N = F_g = 4.9 N$ (2sf)

b) What is the force of friction?

$F_N = 4.9 N$
$\mu = 0.35$
$F_F = ?$

$F_F = \mu F_N$
$= (0.35)(4.9 N) = 17 N$ (2sf)

Ex#2. It takes 50.0 N to pull a 6.00 kg object along a desk. What is the coefficient of friction?

$F_F = 50.0 N$
$F_N = F_g = mg$
$= (6.00 kg)(9.81 N/kg)$
$= 58.9 N$
$\mu = ?$

$F_F = \mu F_N$

$\mu = \frac{F_F}{F_N}$

$= \frac{50.0 N}{58.9 N} = 0.849$ (3sf)

Ex#3. The coefficient of friction between a wooden block and a desk is 0.20. If a force of 0.75 N is needed to pull the block at a constant speed, determine the mass of the block.

$\mu = 0.20$
$F_F = 0.75 N$
$F_N = ?$

$F_F = \mu F_N$

$F_N = \frac{F_F}{\mu} = \frac{0.75 N}{0.20} = 3.75 N$

$F_g = F_N = 3.75 N$
$g = 9.81 N/kg$
$m = ?$

$F_g = mg$

$m = \frac{F_g}{g} = \frac{3.75 N}{9.81 N/kg} = 0.38 kg$ (2sf)