Topic 2.2

The motion of objects can be described precisely in terms of their distance travelled, displacement, speed, velocity and acceleration. However what actually makes a body move? Can we predict the motion of objects?

Forces

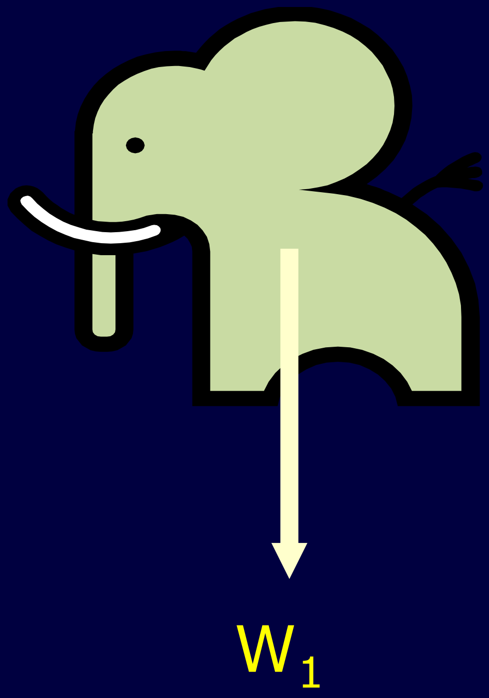
Contents

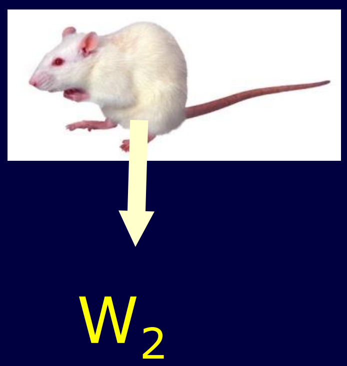
- Objects as Point Particles
- Free-Body Diagrams
- Translational Equilibrium
- Newton’s Laws of Motion
- Solid Friction

Weight

Weight

The gravitational force that a large body, like a planet, exerts on a body.





$$W = mg$$

W = weight

m = mass of body

g = gravitational acceleration

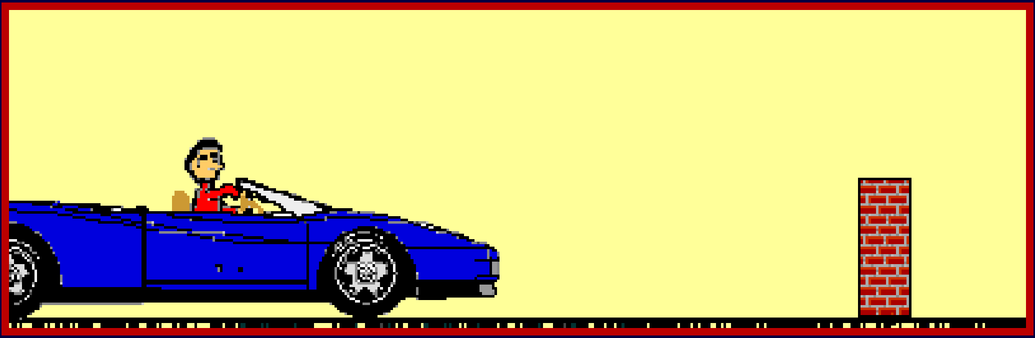
Balanced and Unbalanced forces

What is a force ?

A force is a push or a pull. It is a vector and has both magnitude and direction.

Newton's first law of motion

An object at rest will remain at rest and an object in motion will continue in motion at constant speed in a straight line in the absence of a net force acting on it (when the net force acting on it is zero).



Forces

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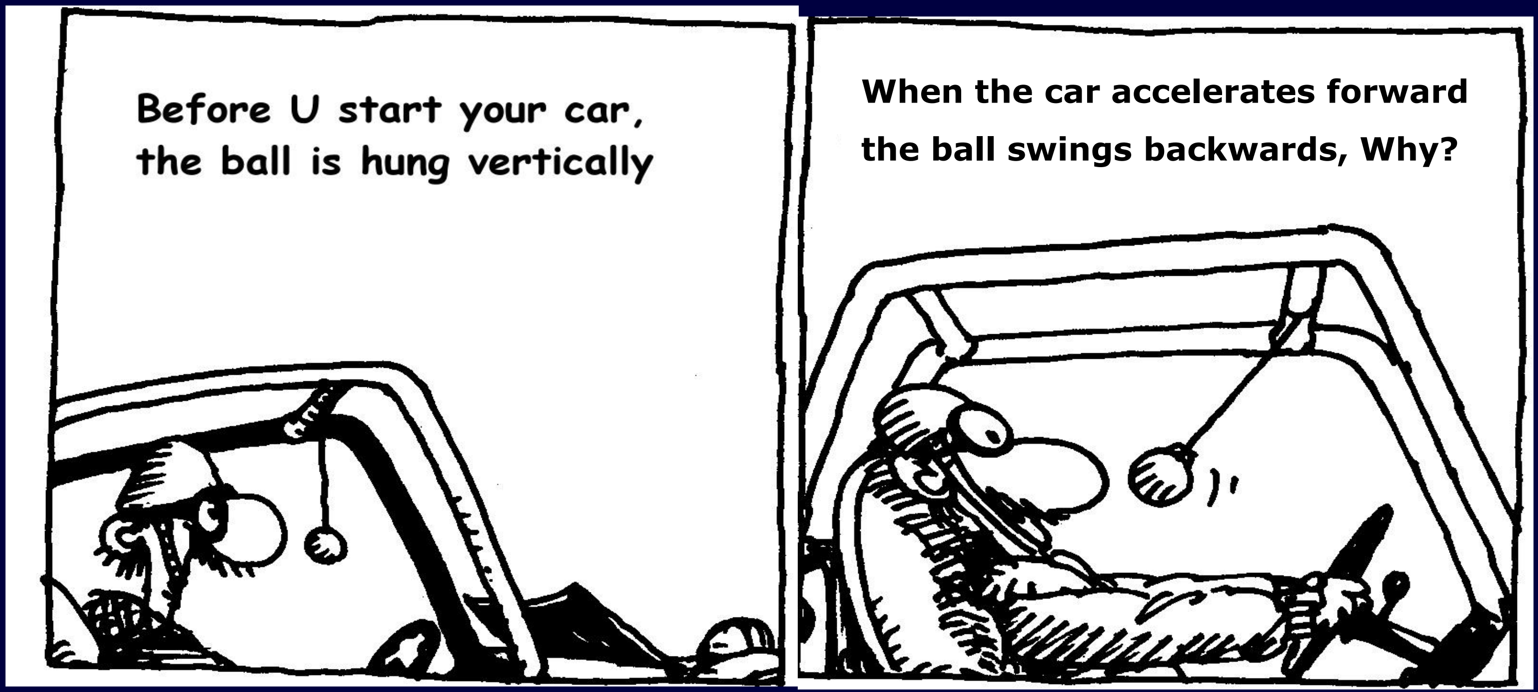
Mass

State of Inertia

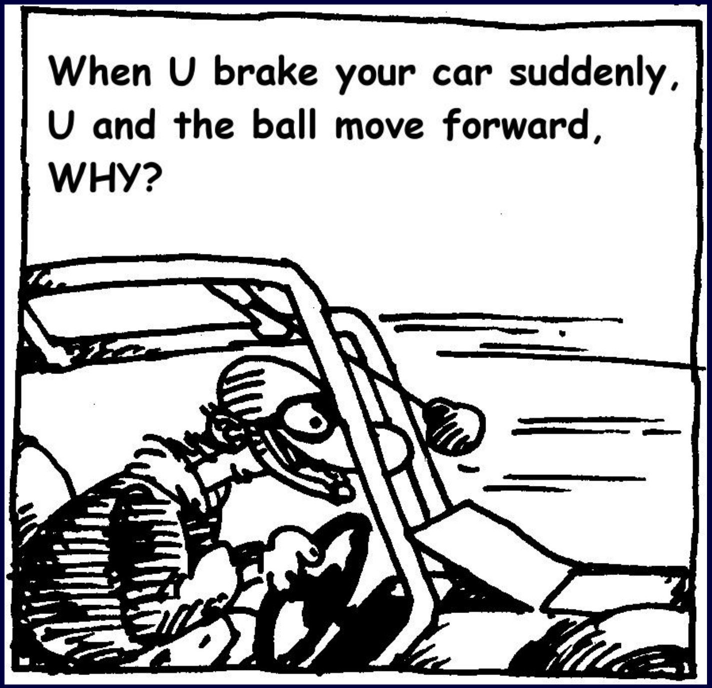
- When a body of matter is stationary, it needs a force to make it start moving
- The <u>bigger</u> the mass, the <u>bigger</u> the force needed
- Masses have inertia, a reluctance to start moving



Mass

State of Inertia

- When a body of matter is moving, it needs a force to stop it
- The <u>bigger</u> the mass, the <u>bigger</u> the force needed
- Masses have inertia, a reluctance to stop moving



Question:

Do you know why you need to put on a seat belt in a car?

Mass

State of Inertia

The mass (m) of a body of matter is a quantitative measure of its inertia,

i.e., its resistance to a change in the state of rest or motion of the body, when a force is applied.

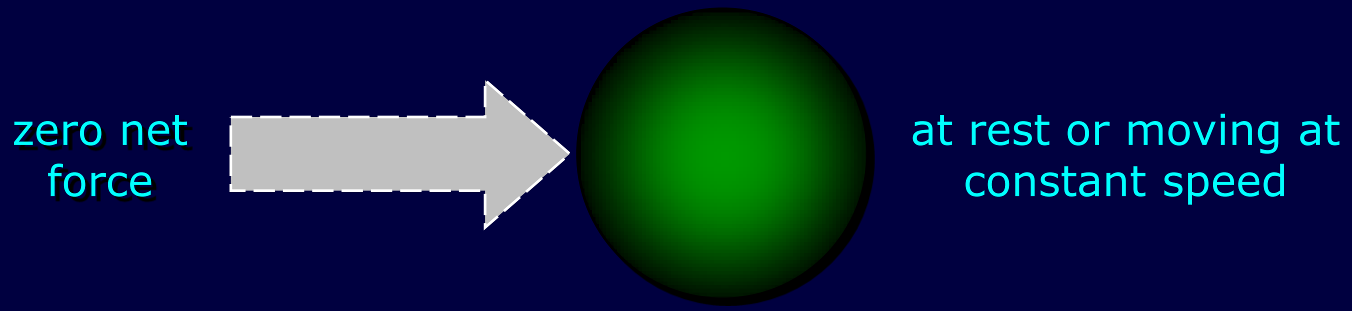
Balanced and Unbalanced forces

Balanced forces

When all forces are balanced, there is 'no net force'.

Newton's first law of motion means that when no net force acts on a body, the body will continue with whatever motion it has.

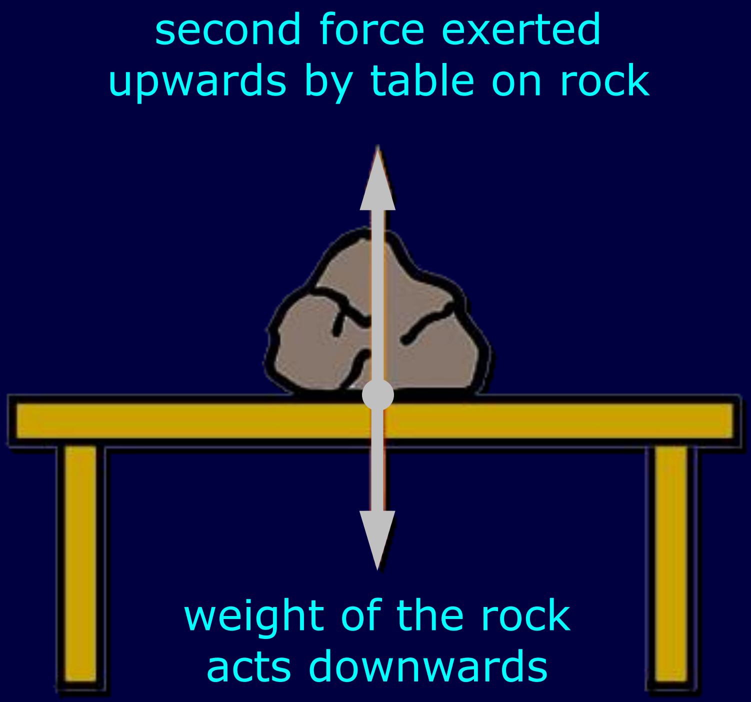
- if it is at rest, it will remain at rest
- if it is moving, it will continue moving at constant speed in a straight line



Balanced and Unbalanced forces

Effects of balanced forces on bodies

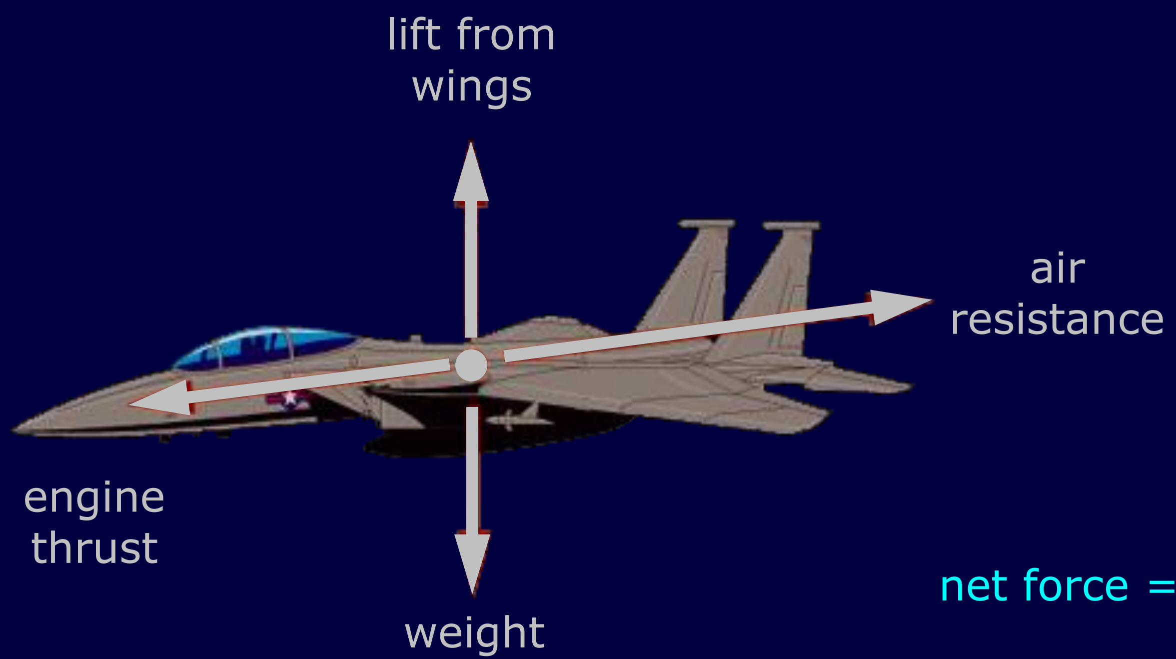
When the rock is not moving, it is at rest. The net force acting on it is zero.



balanced forces on a rock

Balanced and Unbalanced forces

Effects of balanced forces on bodies



net force = 0

constant height: weight of plane is balanced by lift from wings

constant velocity: air resistance is balanced by thrust of engines

Balanced and Unbalanced forces

Net force

When there are a number of forces acting on an object, these forces can be replaced with a single force called **net force** or **resultant force**.

For parallel forces, net force can be calculated by simply adding or subtracting the forces.

Forces acting on a body	**Net force**
2 N ← A → 8 N	A → 8 – 2 = 6 N
B → 8 N; B → 2 N	B → 8 + 2 = 10 N
8 N ← C → 8 N	C No net force
3 N ← D; 8 N ← D; D → 5 N	8 + 3 - 5 = 6 N ← D

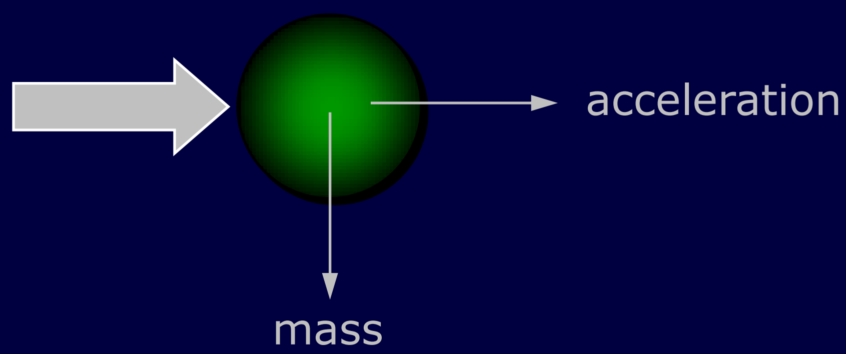
Balanced and Unbalanced forces

Newton's second law of motion

The rate of change of momentum of a body is directly proportional to the net force acting on it and takes place in the direction of the force.

The direction of the force is the same as that of the object's acceleration.

We know, $F = ma$



force = mass x acceleration

Balanced and Unbalanced forces

Newton's second law of motion

The rate of change of momentum of a body is directly proportional to the net force acting on it and takes place in the direction of the force.

$$p = mv$$

p = momentum

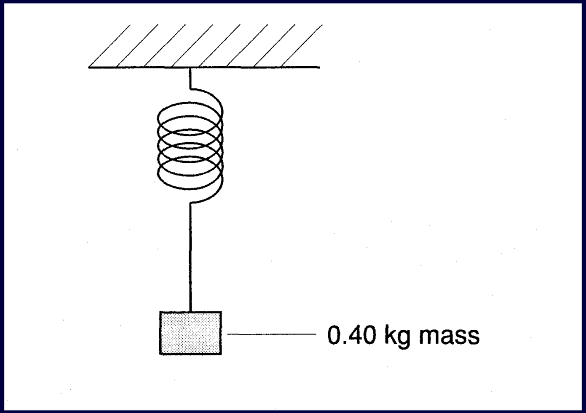
m = mass of body

V = velocity of body

$$F = \frac{\Delta p}{\Delta t}$$

Examples

1. The diagram shows a 0.40 kg mass hanging at rest from a spring.



(a) Draw an arrow showing the line of action and the direction for each of the two forces that act on the mass. Write the name of the force next to each arrow.

(b) The gravitational field strength is 10 Nkg^{-1}. Calculate the values of the two forces you have drawn in (a).

(c) The mass is pulled downwards and then released. Explain, in terms of any changes in the forces acting on the mass, why the mass accelerates upwards.

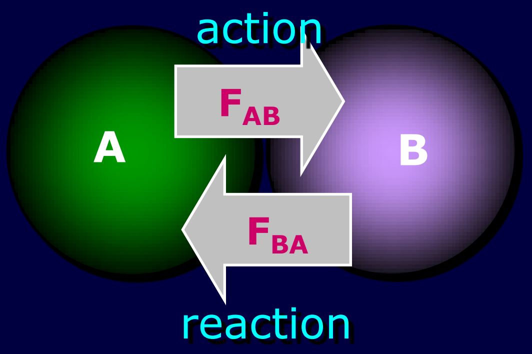
2. A box sits at rest on a rough 30^{o} inclined plane. Draw the free-body diagram, showing all the forces acting on the box. How would the diagram change if the box were after an initial push (a) sliding down the plane, (b) sliding up the plane?

Balanced and Unbalanced forces

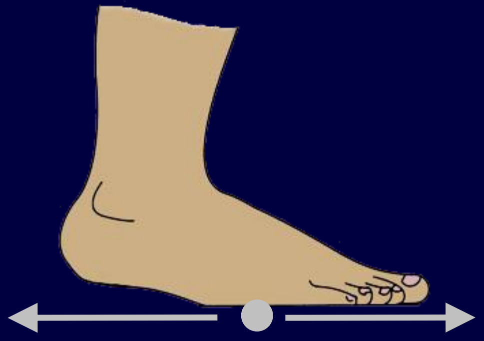
Newton's third law

When two bodies A and B interact, the force that A exerts on B is equal and opposite to the force that B exerts on A.

- forces always occur in pairs
- action and reaction act on different bodies



$$F_{AB} = - F_{BA}$$



force of foot pushes the ground backwards

force of ground pushes the foot forward

More examples of action-reactions pairs of forces

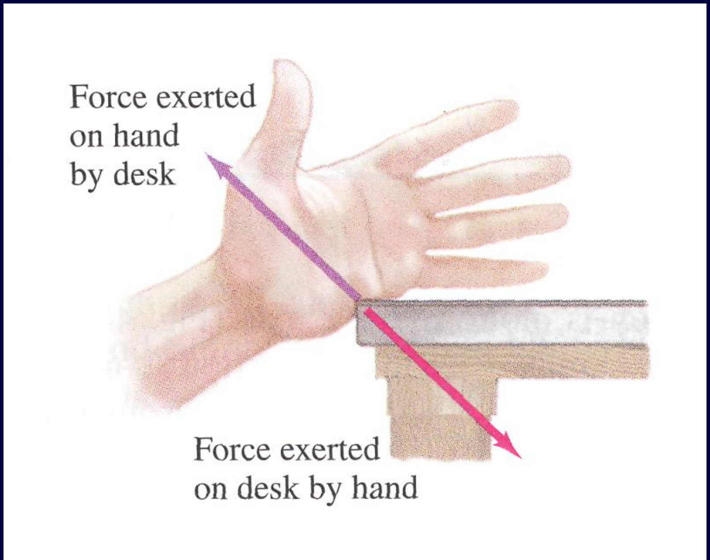
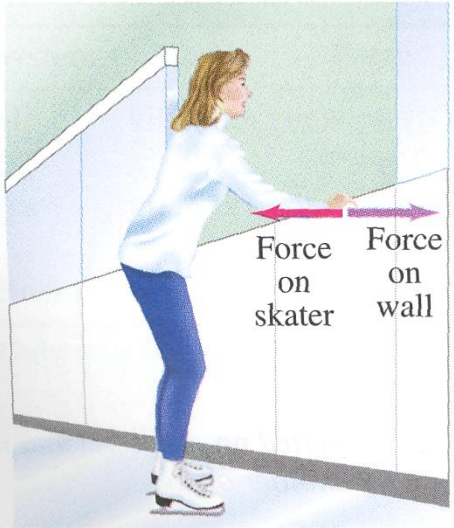


FIGURE 4–9 An example of Newton's third law: when an ice skater pushes against the wall, the wall pushes back and this force causes her to accelerate away.



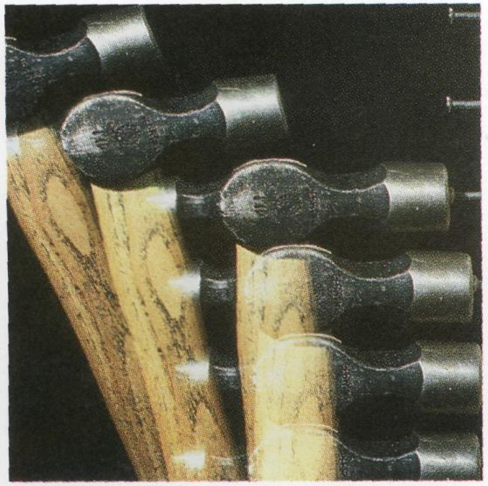
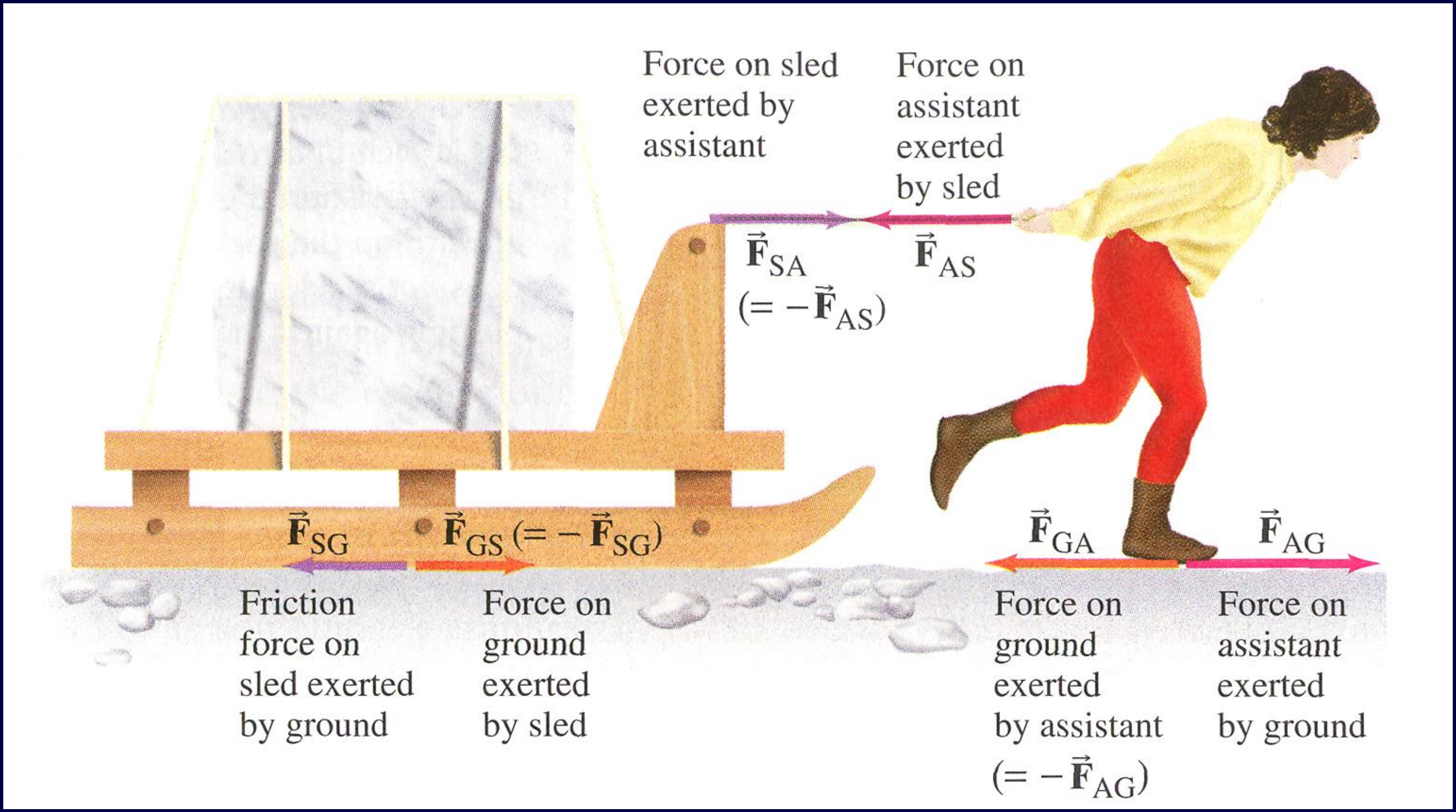


FIGURE 4–7 A hammer striking a nail. The hammer exerts a force on the nail and the nail exerts a force back on the hammer. The latter force decelerates the hammer and brings it to rest.

More examples of action-reactions pairs of forces



Balanced and Unbalanced forces

Newton's third law

Example

A man of mass of 80 kg is inside a lift. Determine the tension in the cable of the lift; when the lift

(a) is at rest [785 N]

(b) rises with a constant velocity of 2.0 m s^{-1} [785 N]

(c) descends with a constant velocity of 2.0 m s^{-1} [785 N]

(d) rises with a constant acceleration of 2.0 m s^{-2} [945 N]

(e) descends with a constant acceleration of 2.0 m s^{-2} [625 N]

(Take g = 9.81 m s^{-2})

Friction

EW

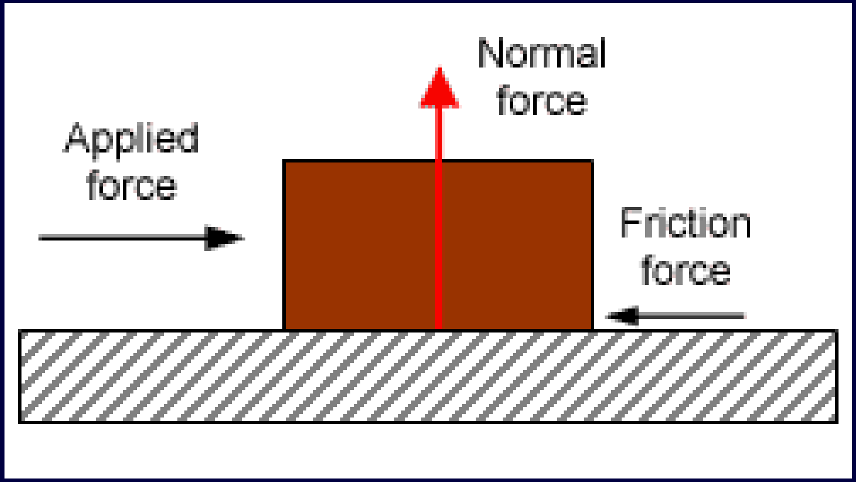
Factors affecting Friction

•Friction is the force that opposes the relative motion of two surfaces.

•It arises because the surfaces involved are not perfectly smooth on the microscopic scale.

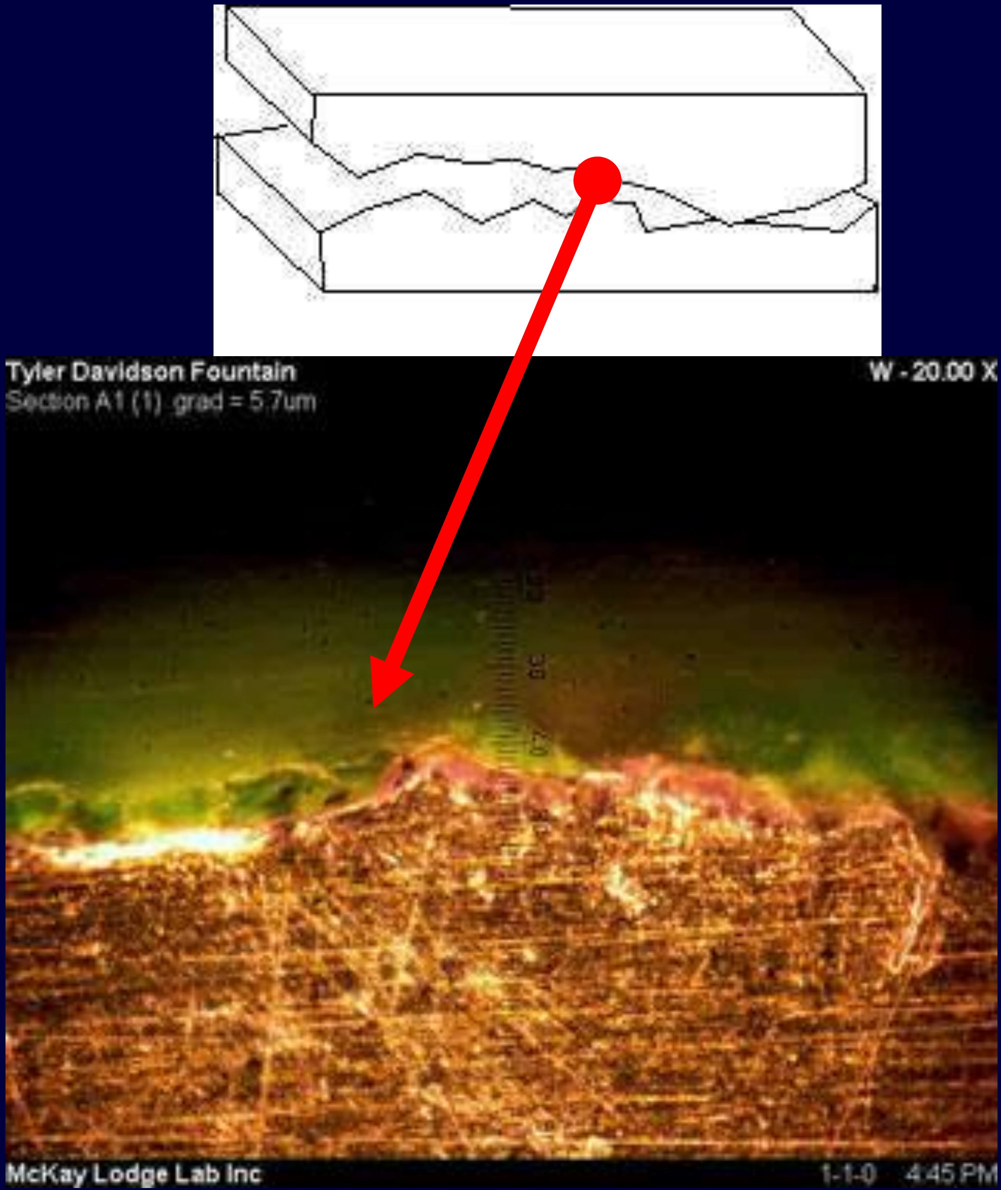
•If the surfaces are prevented from relative motion (they are at rest) then this is an example of static friction.

•If the surfaces are moving relative to each other, then it is called dynamic friction (or kinetic friction).



Factors affecting Friction

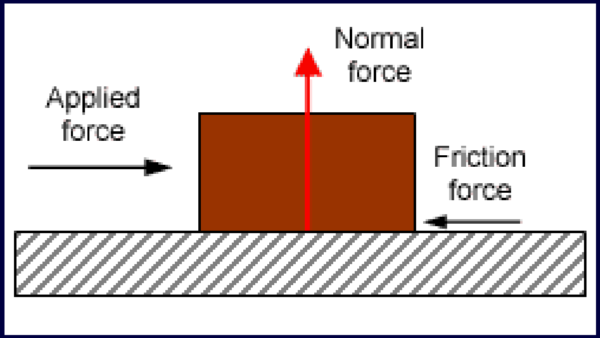
On a microscopic scale, notice that the surfaces are prevented from relative motion due to the imperfections and unevenness of the surfaces.



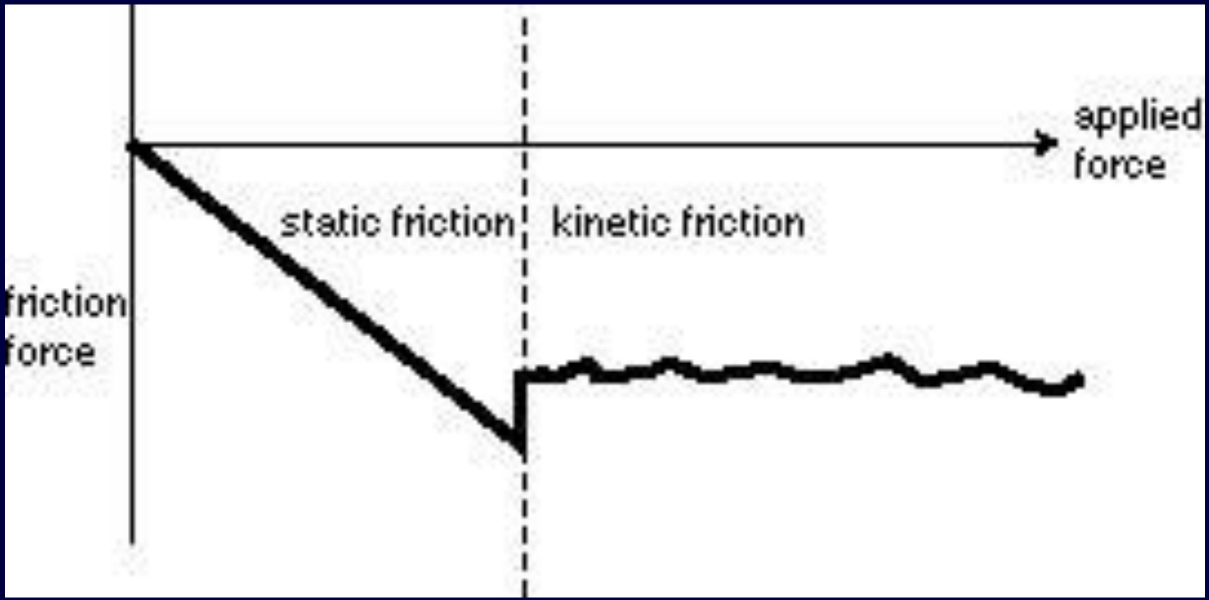
Factors affecting Friction

We choose a coordinate system in which the applied force, i.e. the force trying to move the objects, is positive. The friction force is then negative, since it is in the opposite direction.

As you increase the applied force, the force of static friction increases to match it and cancel it out, until the maximum force of static friction is surpassed. The surfaces then begin slipping past each other, and the friction force becomes smaller in absolute value.

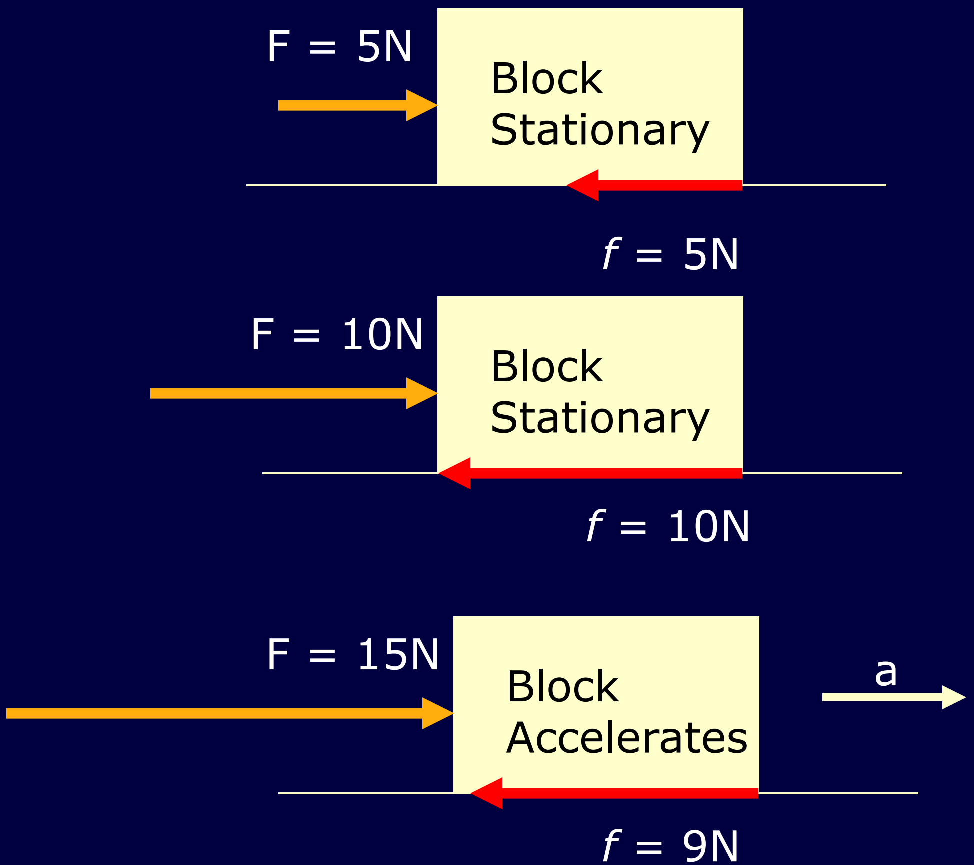


Positive direction



Factors affecting Friction

Up to a certain maximum force, $F_{max,}$ the resultant force is ZERO because the block does NOT move.

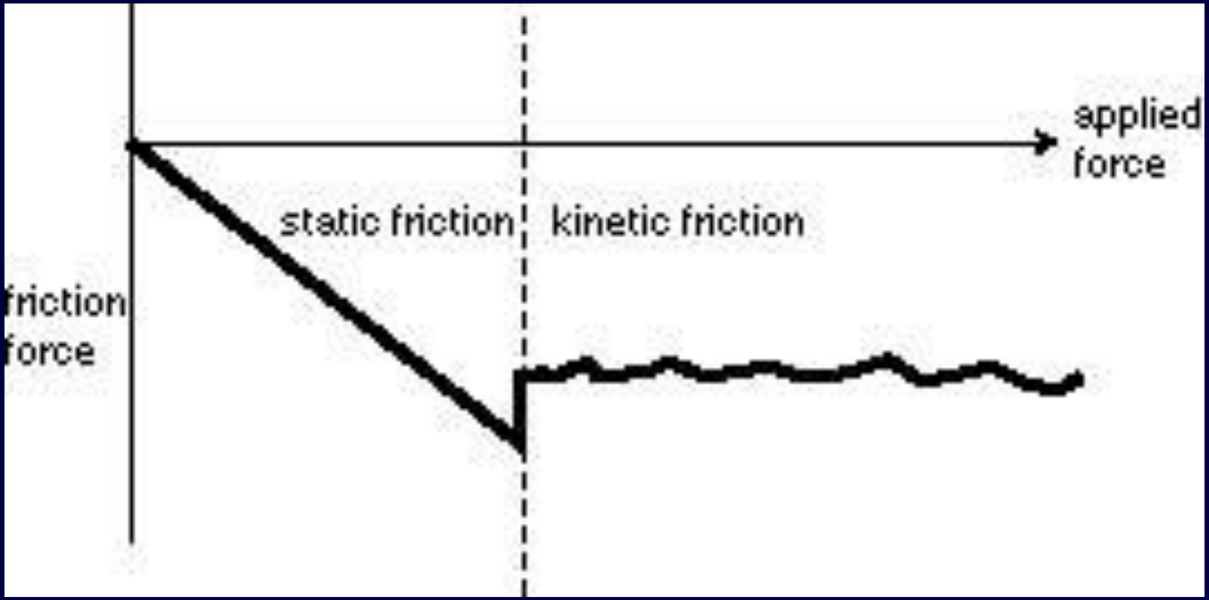


The value of F_{max} depends upon:

- The nature of the two surfaces in contact
- The normal reaction between the two surfaces

If the two surfaces are kept in contact by gravity, the value of F_{max} does NOT depend on the area of contact.

Dynamic/Kinetic Friction



Once the object has started moving, the maximum value of friction slightly reduces.

For two surfaces moving over one another, the dynamic frictional force remains roughly constant even if the speed changes slightly.

Coefficient of Friction

Experimentally, the maximum frictional force and the normal reaction force are proportional.

$$f = \mu N$$

f = maximum frictional force
μ =coefficient of friction
N = normal reaction force

- Since the maximum value for dynamic friction is less than the maximum value for static friction, the coefficient of dynamic friction will be less than the coefficient of static friction. Therefore $\mu_d < \mu_s$

Static friction $\mathbf{F_f \leq \mu_s R}$
can vary from 0 to maximum value

Dynamic friction $\mathbf{F_f = \mu_d R}$

Coefficient of Friction

- The coefficient of friction is a ratio between two forces – therefore it has no units.

$$\mu = \frac{f}{N}$$

- If the surfaces are perfectly smooth, then the maximum friction is zero.

$$\mu = 0$$

- $\mu < 1$ always unless the two surfaces are effectively stuck together. In other words, if we apply a force, there will be a point in which the applied force will overcome the static frictional force.

Coefficient of Friction

Materials	μ [static]	μ [kinetic]
Aluminium - Steel	0.61	0.47
Car tyre - Asphalt	0.90	0.72
Copper – Steel	0.53	0.36
Glass on Glass	0.94	0.4
Steel – Steel	0.74	0.54
Steel - Teflon	0.05	0.05