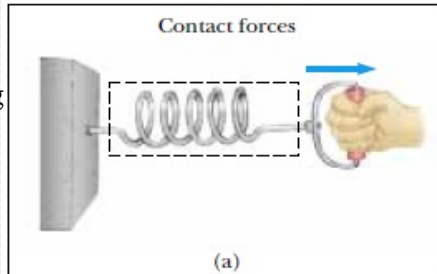# Lecture 3
The Laws of Motion

OUTLINE

- 5.1 The Concept of Force

- 5.2 Newton's First Law and Inertial Frames

- 5.3 Mass

- 5.4 Newton's Second Law

- 5.5 The Gravitational Force and Weight

- 5.6 Newton's Third Law

- 5.8 Forces of Friction

- 5.9 Newton's Law of Universal Gravitation.

The Concept of Force

contact forces

field forces

a) When a coiled spring is pulled, the spring stretches.

b) When a stationary cart is pulled hard that friction is overcome, the cart moves.

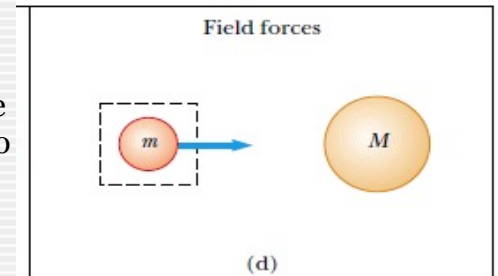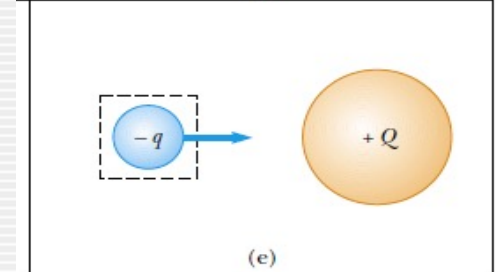c) When a football is kicked, it is both deformed and set in motion.
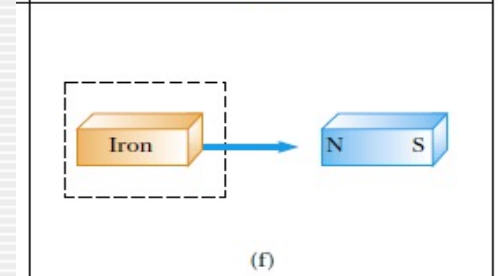
d) The gravitational force of attraction between two objects.

e) electric force that one electric charge exerts on another; example: charges of the electron and proton that form a hydrogen atom
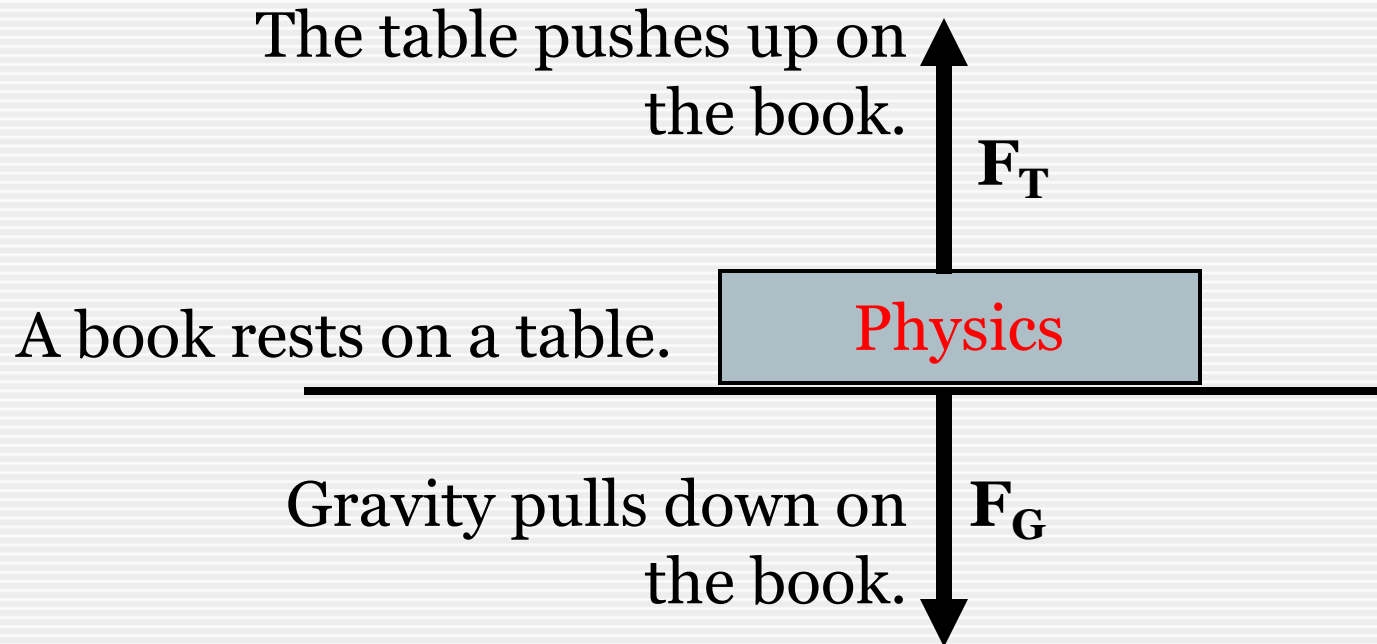
f) Force a bar magnet exerts on a piece of iron.

The Concept of Force

- The net force (or resultant force) acting on an object is defined as the vector sum of all forces acting on the object.

- If the net force exerted on an object is zero, the acceleration of the object is zero and its velocity remains constant.

- When the velocity of an object is constant (including when the object is at rest), the object is said to be in equilibrium.

What is Zero Net Force?

The table pushes up on the book.

$\mathbf{F_T}$

A book rests on a table.

Physics

Gravity pulls down on the book.

$\mathbf{F_G}$

Even though there are forces on the book, they are balanced. Therefore, there is no net force on the book.

$$\Sigma F = 0$$

Newton's First Law

"An object at rest will stay at rest, and an object in motion will stay in motion at constant velocity, unless acted upon by an unbalanced force"

$$\sum F = 0$$

1ˢᵗ Law

In another words:

If <u>no</u> **net force** acts on a body, the body's velocity cannot change(velocity=constant) ;
that is, the body cannot accelerate (<u>acceleration</u> on an object <u>is zero</u>)... which means:

- it cannot turn,

- it cannot speed up,

- it cannot slow down.

According to Newton's first law

(law of inertia):

Inertia is the tendency of an object to resist changes in its velocity: whether in motion or motionless.

The inertia of an object is directly proportional to its mass. The greater the mass the greater the inertia and the lower the mass the lower the inertia.

Objects keep on doing what they're doing.
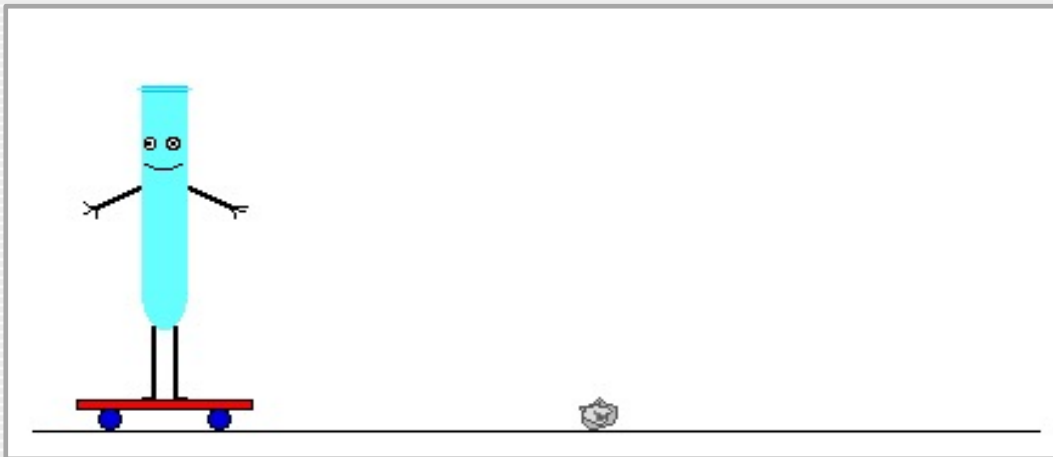
This law is the same reason why you should always wear your seatbelt.

Because of inertia, objects (including you) resist changes in their motion. When the car going 80 km/hour is stopped by the brick wall, your body keeps moving at 80 m/hour.

2ⁿᵈ Law

Newton's second law: the net force on a body is equal to the product of the body's mass and its acceleration.
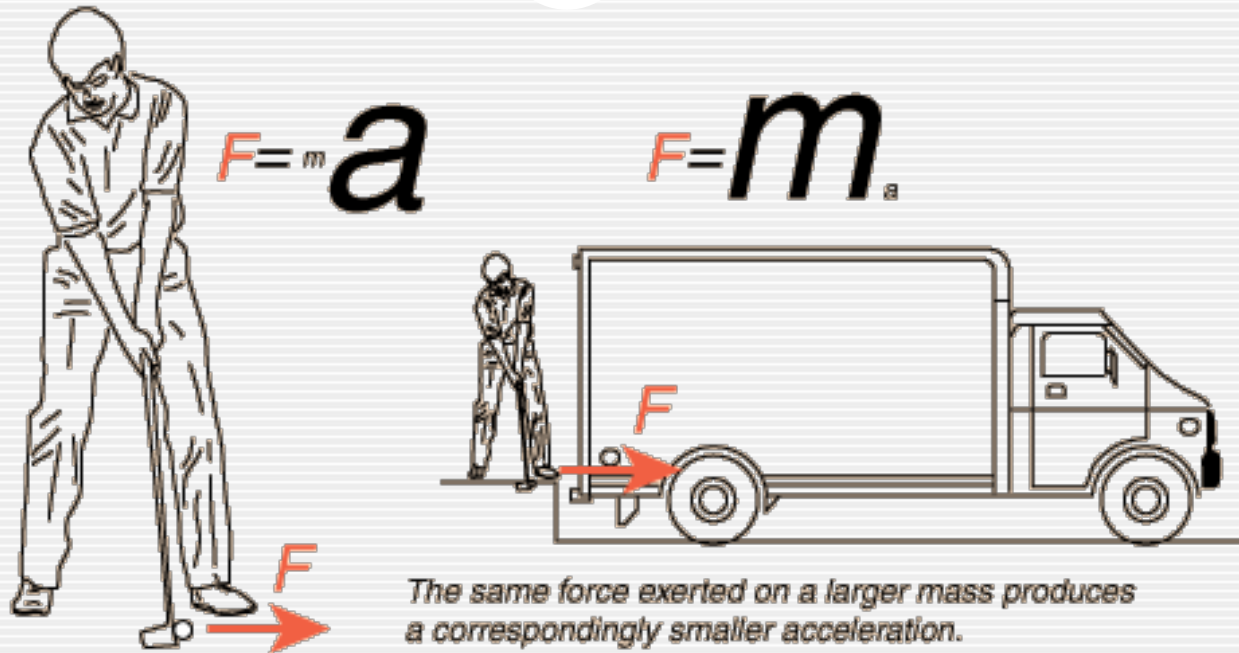
$$F_{net\ external} = ma$$

Net force on object = mass of object x acceleration

Units of force:

Newton (in SI system) where; 1 N = 1 kg . m /s²

Definition: 1 N is the force required to accelerate

a 1 kg mass   at a rate of 1 m/s²

For example...

The same force exerted on a larger mass produces a correspondingly smaller acceleration.

The <u>acceleration</u> of an object is directly proportional to the <u>force</u> acting on it.
The magnitude of the <u>acceleration</u> of an object is inversely proportional to its <u>mass</u>.

According to Newton's second law

Acceleration **is produced when**
a force acts on a mass.

- What does this mean?

heavier objects require more force to move the same distance as lighter objects.

MORE MASS MEANS MORE FORCE NEEDED TO ACCELERATE.

This is an example of how Newton's Second Law works:

Mike's car, which weighs **1,000 kg**, is out of gas. Mike is trying to push the car to a gas station, and he makes the car go **0.05 m/s²**. Using Newton's Second Law, you can compute how much force Mike is applying to the car.
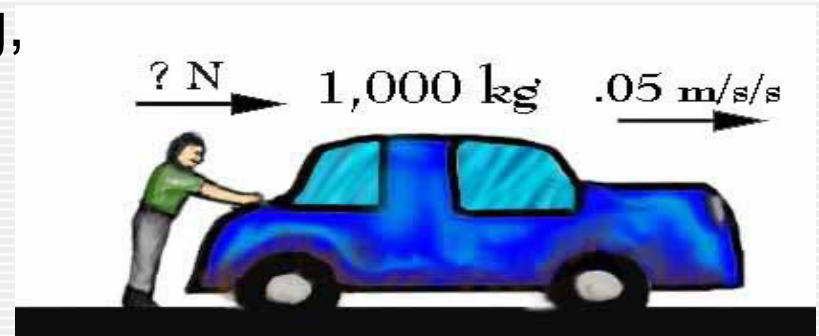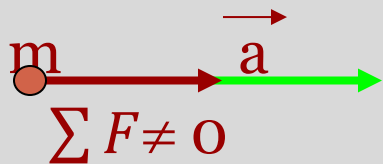

Answer

F=1,000 X 0.05 = 50 Newton

Analysis Model for Problem Solving

Particles Under a Net Force

If a particle of mass m experiences a nonzero net force, its acceleration is related to the net force by Newton's second law :

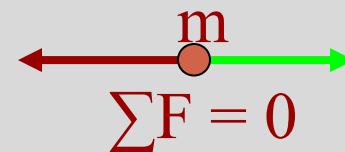$$\sum \vec{F} = m\vec{a}$$

m $\quad \vec{a}$

$$\sum F \neq 0$$

Particles in Equilibrium

If a particle maintains a constant velocity (so that a= o), which include a velocity of zero, the forces on the particle balance and Newton's first law is applied.

$$\sum \vec{F} = 0$$
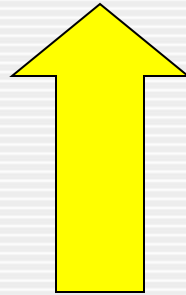
$$\vec{a} = 0$$

m

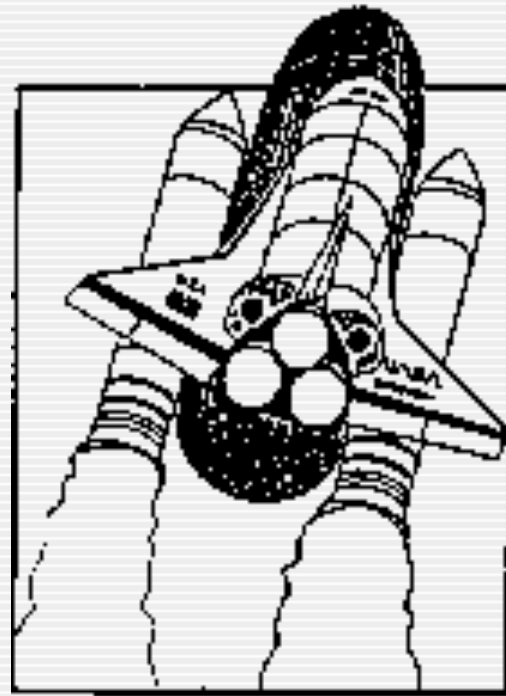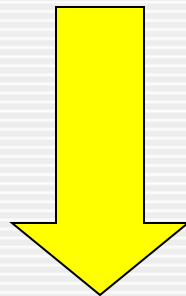$$\sum F = 0$$

Newton's 3rd Law

"For every action, there is an equal and opposite reaction."

Reaction

Action

Newton's 3rd Law

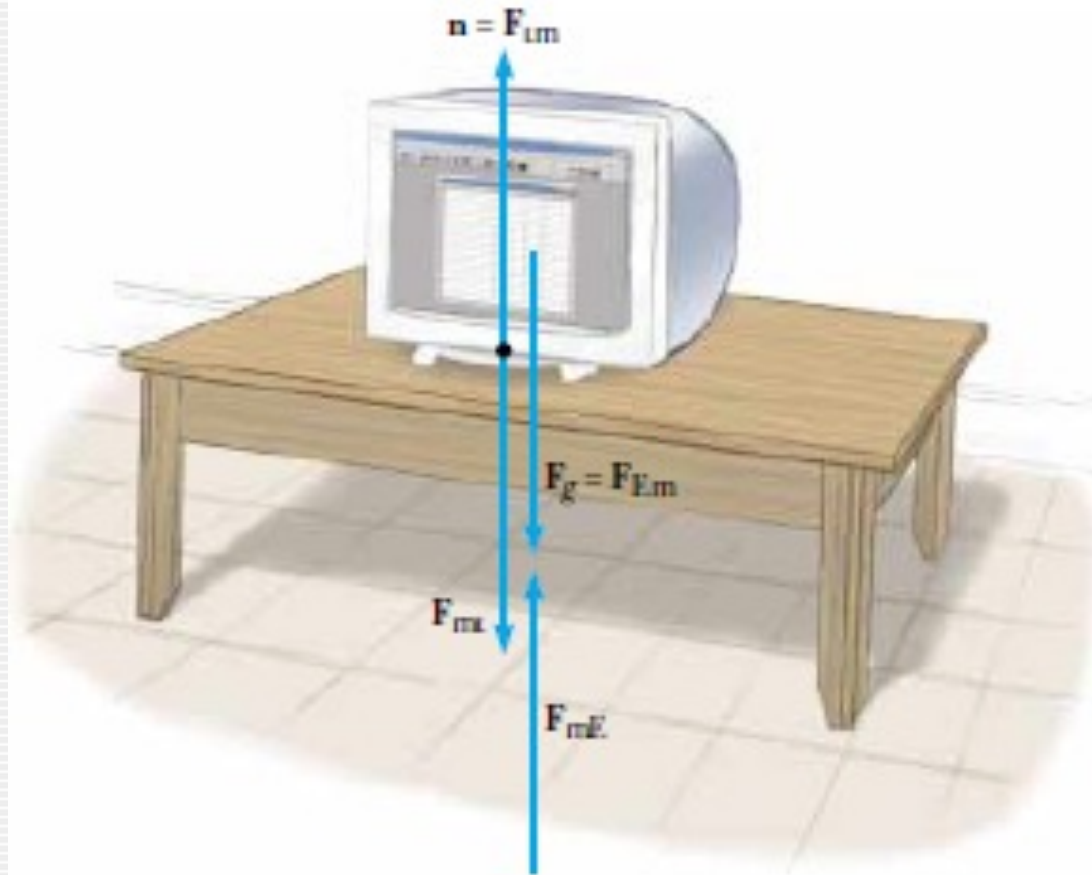The Newton's Third Law interaction is always between two objects.

For example :   **A pushes / pulls B.**

B pushes / pulls A.

One of these forces is called the action force, and the other one is called the reaction force - it doesn't matter which is which. For example, if:

- **You push book. (Action force)**

then Newton's Third Law says that:

- **Book pushes you. (Reaction force)**

Newton's 3rd Law

When a computer monitor is at rest on a table, the forces acting on the monitor are **the normal force n and the gravitational force F$_g$.** *The reaction to n is the* **force F$_{mt}$ exerted by the monitor on the table. The** reaction to F$_g$ *is the force* **F$_{mE}$ exerted by the monitor on the Earth.**

Newton's Law of Universal Gravitation

Newton's law of universal gravitation

states that a particle attracts every other particle in the universe using a force (F_g) that is Directly Proportional to the product of their masses (m1 , m2), and Inversely Proportional to the square of the distance between them (r^2).
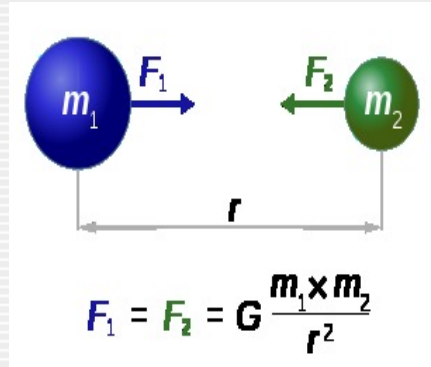
$$F_g = G\frac{m_1 m_2}{r^2}$$

where _G is a constant, called the universal gravitational constant, that has been measured_ experimentally. Its value in SI units is

$$G = 6.673 \times 10^{-11} \ N \cdot m^2/kg^2$$

The Gravitational Force and Weight

❖ all objects are attracted to the Earth.

❖ The attractive force exerted by the Earth on an object is called <u>the gravitational force F_{g-}</u>.

❖ *This force is <u>directed</u>* toward the center of the Earth, and its <u>magnitude</u> is called the weight of the object.

What is the difference between mass and weight?

Mass

1. Is always constant at any place and time.
2. Is measured in **Kilograms** in SI unit
3. Can never be zero.
4. Is an intrinsic property of a body and is independent of the body's surroundings and of the method used to measure it.

Weight

1. Depends on:
   a. gravity at the place,
   b. Mass of the object which is attracting it.
2. Is measured in **Newton** not in kilograms.
3. Can also be zero.
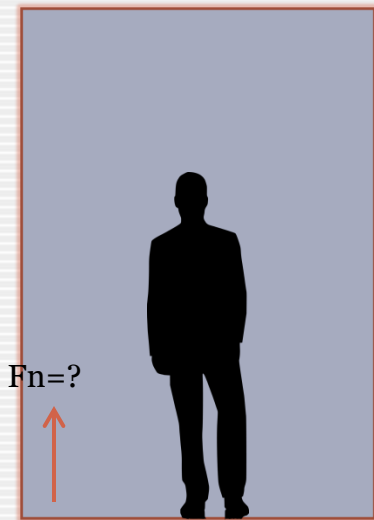4. Is measured using scales.

Weight & Mass

$$m = \frac{W}{g}$$

Ex. : Man whose weight is 1000 N on the earth has a mass of :

$$m = \frac{W}{g} = \frac{1\,000\,kg\cdot m/s^2}{9.8\,m/s^2} = 102\,kg.$$

The Gravitational Force and Weight

An 80 kg man standing on an elevator that is accelerating upwards at 2 m/s² . Calculate the support force F$_n$ exerted by the elevator floor on the man?

Fn=?
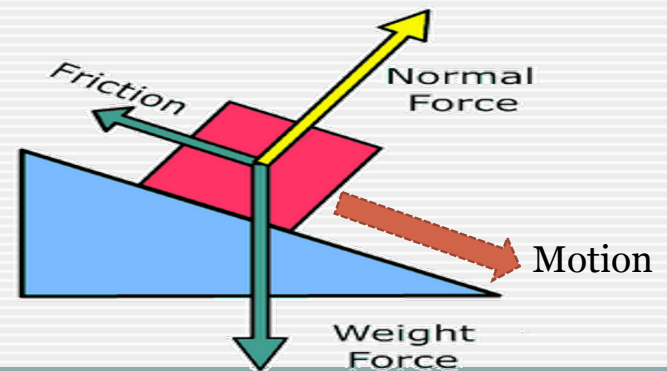
$\vec{a}$

W=mg

$$\sum F = ma$$

$$F_n - mg = ma$$

$$F_n = ma + mg = 944 \text{ N}$$

The Force of Friction

- Friction is a force that is created whenever two surfaces move or try to move across each other.

- Friction acts in a direction parallel to the area of contact.

- Friction always opposes the motion
  or the tendency to move .

The Force of Friction

The force of friction depends upon both

surfaces in contact (μ) and the normal force (F_n).

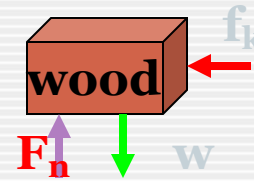A mathematical relationship can be created here:

$$F_f = \mu\, F_n$$

were μ is the friction coefficient.

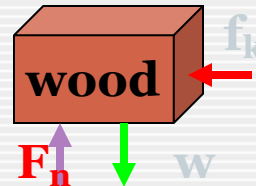** Friction force **does not** depend on the surface area (contact area).

The Force of Friction

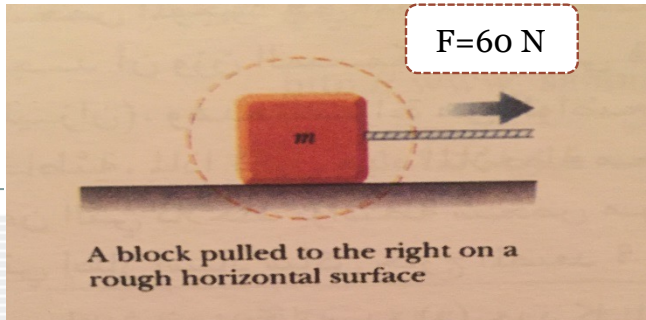Friction is dependant on the texture of both surfaces
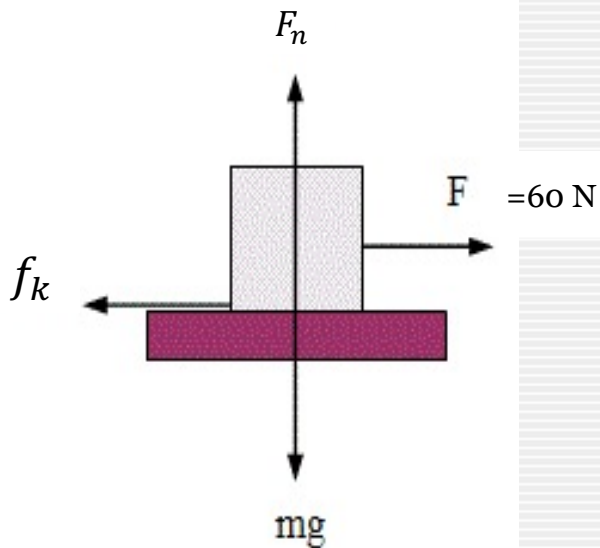

$$\frac{f_k}{F_N} = 0.4$$

$$\mu_k = 0.6$$

example

F=60 N

A block pulled to the right on a rough horizontal surface

F_n

F =60 N

f_k

mg

A 16 kg box is on a rough horizontal surface. A constant 60 N pulling force is applied to the box horizontally.
The coefficient of kinetic friction between the box and the surface is 0.3.
what is the acceleration of the box?

$$\sum F = ma$$

$$\sum F_y = 0 \Rightarrow F_n = mg = 16\times9.8 = 156.8 \text{ N} \qquad (1)$$

$$\sum F_x = ma \Rightarrow \quad 60 - f_k = ma = 16\,a \qquad (2)$$

$$f_k = \mu_k\, F_n = 0.3\times156.8 = 47.04 \text{ N} \qquad (3)$$

By using eq. 3 in eq. 2 we get:

$$60 - 47.04 = 16\,a$$

$$\Rightarrow a = \frac{12.96}{16} = 0.81 \ m/s^2$$

Home Work

- 1. What is the **weight** of a 200 kg object?

- 2. A woman exerts a force of 500 N straight up to lift a 35 kg basket. What is the **acceleration** of the basket?

- 3. An elevator of mass 3000 kg is ascending at a steady speed of 2.0 m/s. What is the **force** in the cable supporting the elevator?

- 4. A 49-N block is pulled by a horizontal force of 50.0 N along a rough horizontal surface at a constant acceleration of 6 m/s². What is the **coefficient of friction**?