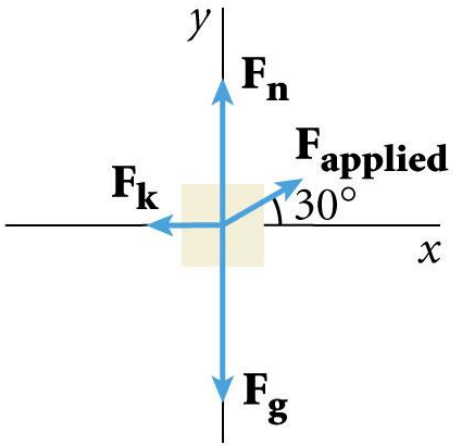
Forces & Laws of Motion

Ch 4 Physics

Forces & the Laws of Motion

- **Objectives**
  - **Describe** how force affects the motion of an object.
  - **Interpret** and **construct** free body diagrams



- **Dynamics** investigates the cause of an objects motion.

- **Force** is an influence on an object that causes the object to accelerate. (Example pushing or pulling)
  - Unit – Newtons (N) – 1 N Force causes a 1 Kg object to accelerate to 1 m/s^2

Forces & the Laws of Motion

- A **Force** is an action exerted on an object which may change the object's state of rest or motion.
  - Causes object to start or stop moving or change direction

- **Forces** can cause **accelerations**

- **2 types of forces**
  - **Contact forces** – physical contact between two objects
    - Ex: Frictional force, normal force, tension, spring force, air resistance
  - **Field force** – No physical contact
    - Ex: Gravity, magnetic force, electric force

Newton's First Law

- **Newton's First Law – Law of Inertia**
  - An object in motion tends to stay in motion; an object at rest tends to stay at rest
  - An object with *no net force acting on it* remains at rest or moves with constant velocity

- **Inertia** – is the resistance an object has to a change in its state of motion
  - The amount of inertia an object has depends on its **mass**
    - Mass is the amount of material in a body (Kg)
    - Weight is a measure of the gravitational force on an object (N)

Newton's 2nd Law

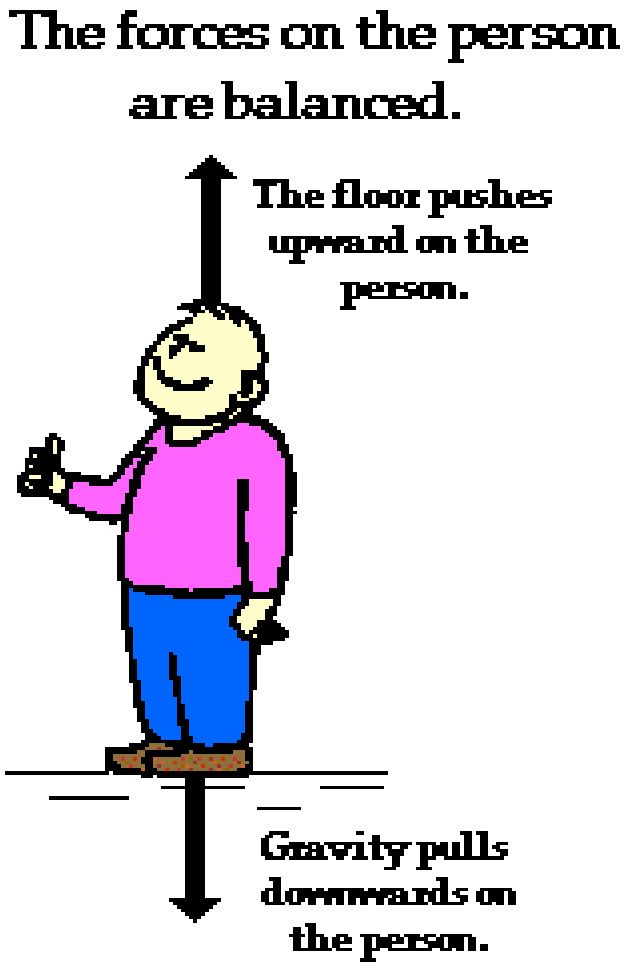
- **Force = mass x acceleration**
  - An object will only accelerate if there is an unbalanced force

- The acceleration of an object is directly proportional to the **net force** acting on the object and inversely proportional to the object's mass.

$$\Sigma \mathbf{F} = m\mathbf{a}$$

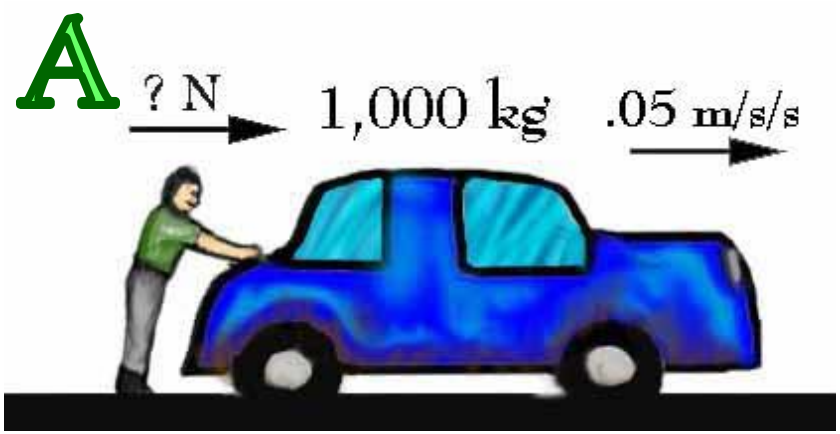
net force = mass × acceleration

Σ **F** *represents the vector* ***sum*** *of all external forces acting on the object, or the net force.*



Newton's 2nd Law

A

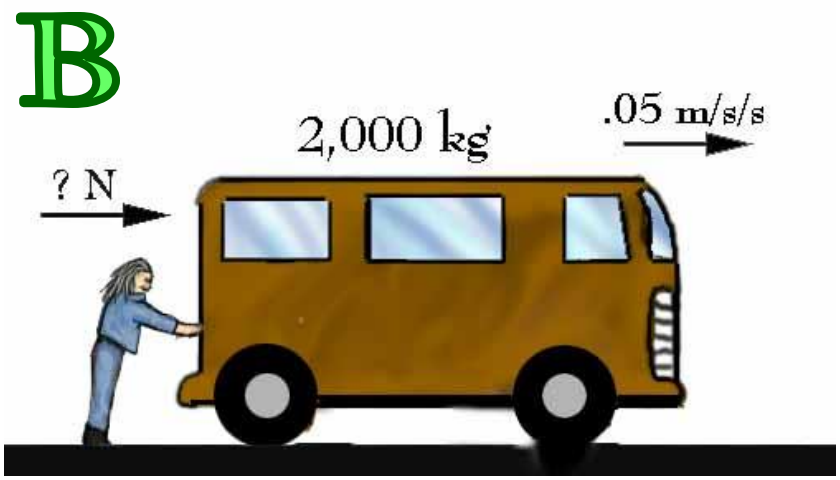


$$f = m \times a$$

F_A = 1000 kg x 0.05 m/s/s

F_A = 50N

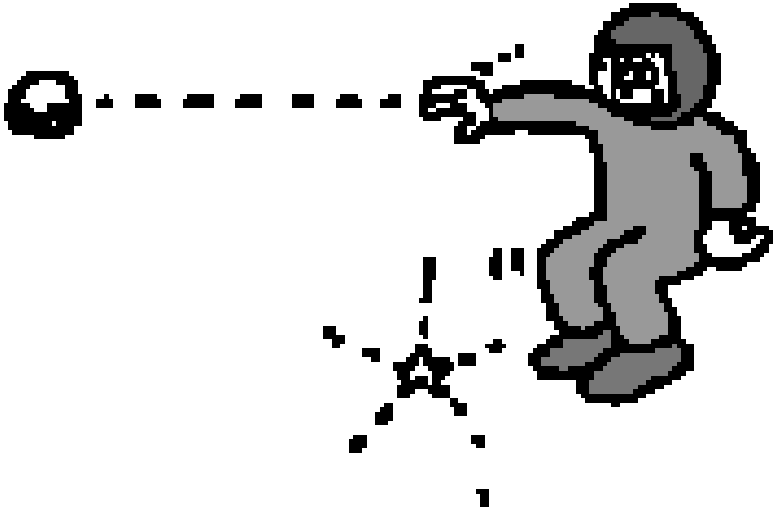
B



F_B = 2000 kg x 0.05 m/s/s

F_B = 100N

Newton's 3rd Law

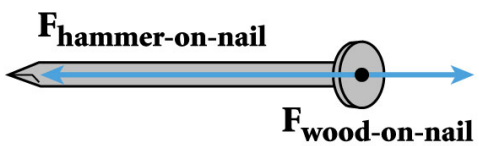


- For every action there is an **equal** and **opposite** reaction
  - The astronaut pushes on the rock and the rock pushes on the astronaut

Action and Reaction Forces

- Action force – force that object 1 exerts on object 2
- Reaction force – force that object 2 exerts on object 1
  - Doesn't matter which is which

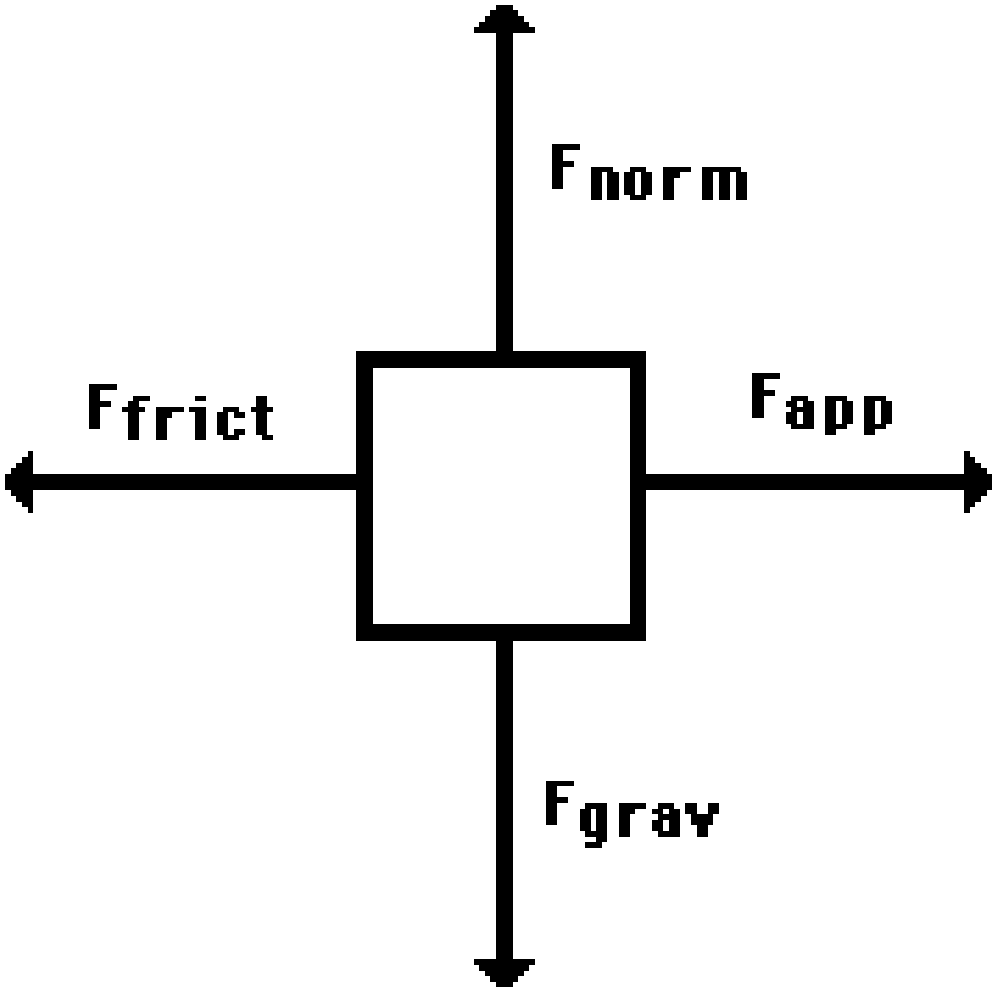
- **Action – Reaction pairs**
  - Each force acts in different objects
  - Do not result in equilibrium
  - Always in pairs



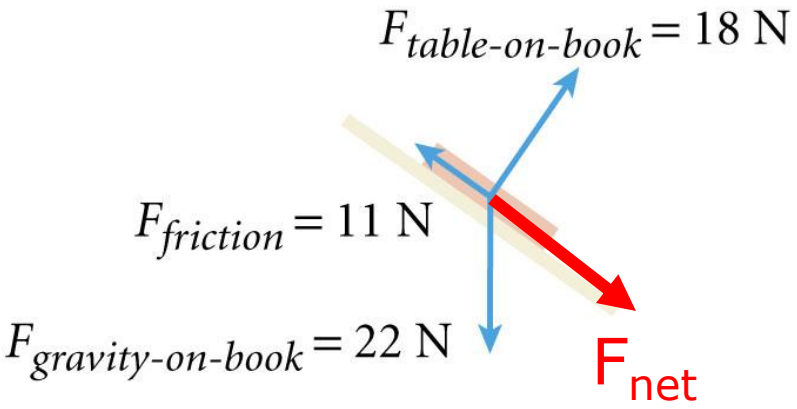
Consider driving a nail into wood with a hammer. The force that the nail exerts on the hammer is equal and opposite to the force that the hammer exerts on the nail. But there is a net force acting on the nail, which drives the nail into the wood.

Free-body diagrams

Free-body diagrams are used to show the relative magnitude and direction of all forces acting on a object.



Free Body Diagrams

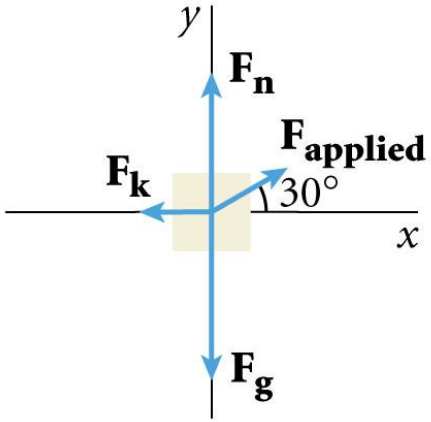


- **Free-body diagrams** – shows all the forces acting on a **single** object.
  - Only shows the forces acting **<u>on</u>** the object
  - The effect of a force depends on both **magnitude** and **direction.** Thus, force is a **vector** quantity
    - Represented by arrows in appropriate direction
- **Net Force F_{net}** - the combination of all the forces that act on an object.

Drawing Free –Body Diagram

- **Normal force F_N**– the force caused by 2 bodies in direct contact.
  - Perpendicular to the plane of contact
  - Normal force on a mass resting on level ground is its weight.

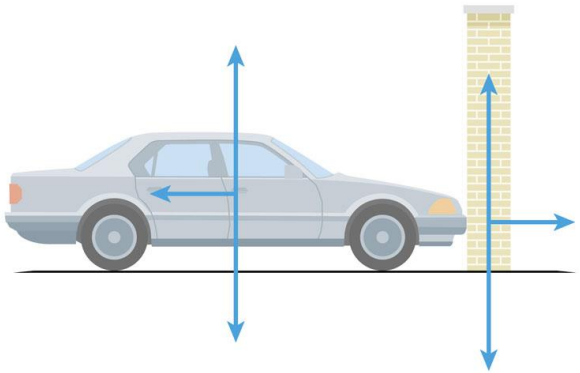
    F_N = mg (mass * gravity)



- **<u>Steps to draw free-body diagrams</u>**
  - Draw a box or simple shape of object
    - In same position – if on inclined plane, so should shape
  - Draw & label vector arrows
    - All arrows are drawn from center of object
  - Choose a coordinate axis system, one that puts the most forces on the axis's

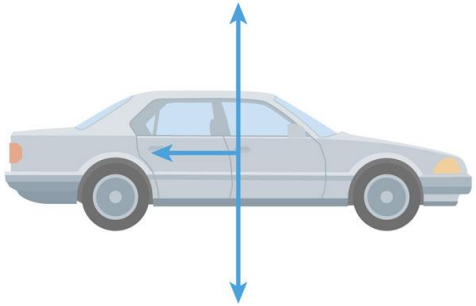
Force Diagram Vs Free-Body Diagram

Force Diagram



In a force diagram, vector arrows represent all of the forces acting in a situation

Free-Body Diagram

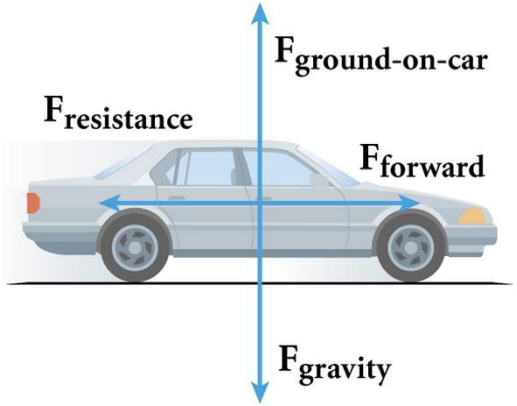


A free-body diagram shows only the forces acting on the object of interest—in this case, the car.

Net Force

- **Newton's first law** refers to the **net force** on an object. The net force is the **vector sum** of all forces acting on an object.

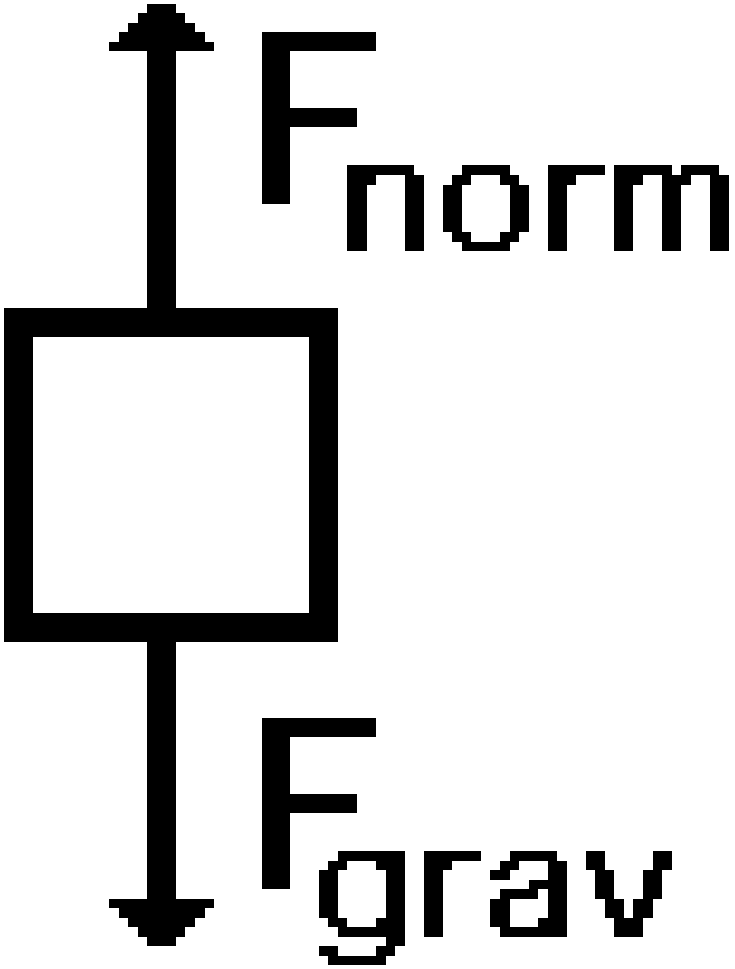
- The **net force** on an object can be found by using the methods for finding resultant vectors.



Problem 1

- A book is at rest on a table top. Diagram the forces acting on the book.

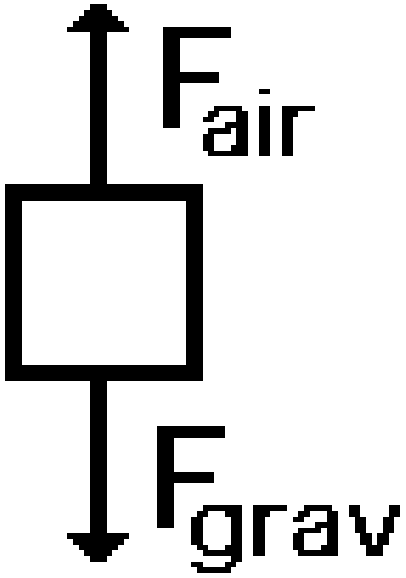
- In this diagram, there are normal and gravitational forces on the book.



Problem 2

A flying squirrel is gliding (no wing flaps) from a tree to the ground at constant velocity. Consider air resistance. A free body diagram for this situation looks like…

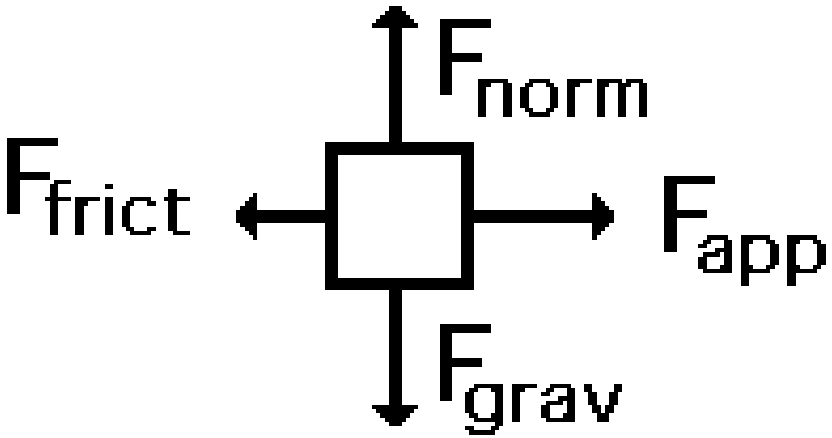
Gravity pulls down on the squirrel while air resistance keeps the squirrel in the air for a while.



Problem 3

A rightward force is applied to a book in order to move it across a desk. Consider frictional forces. Neglect air resistance. Construct a free-body diagram.

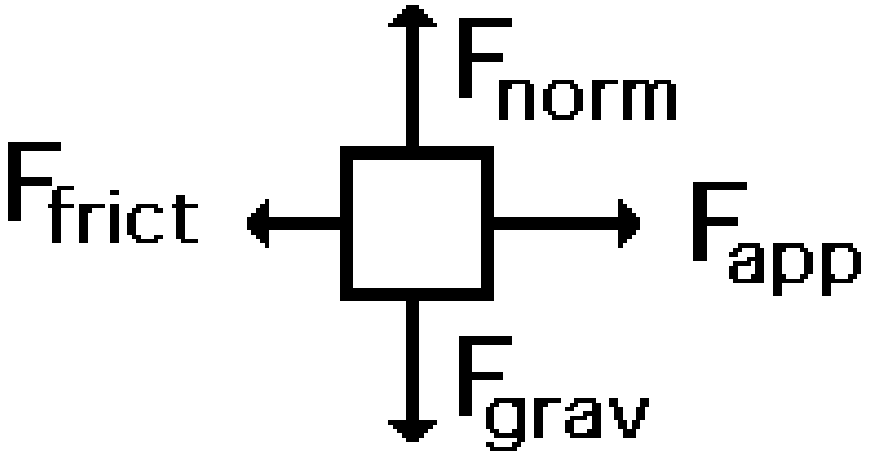
Note the larger applied force arrow pointing to the right since the book is accelerating to the right. Friction force opposes the direction of motion. The force due to gravity and normal forces are balanced.



Problem 4

A man drags a sled across loosely packed snow with a rightward acceleration. Draw a free-body diagram.

The applied force arrow points to the right and is larger than the frictional force since the object is accelerating. Since the sled is on the ground, the normal and gravitational force are balanced.

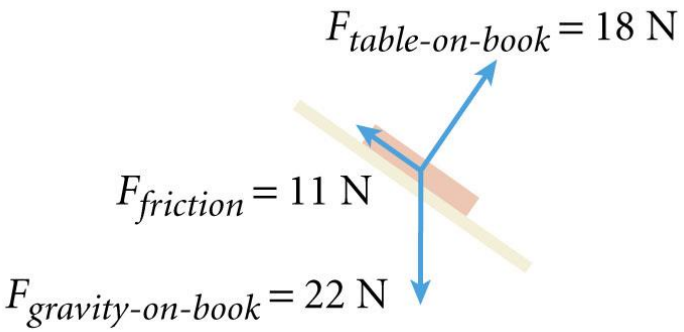


Sample Problem - complex

Determining Net Force

Derek leaves his physics book on top of a drafting table that is inclined at a 35° angle. The book has a force of 22N, the force of friction is 11N, and the normal force is 18N. Find the net force acting on the book.

1. Draw the free-body diagram and identify the variables.



Given:

$F_{gravity} = F_g = 22$ N

$F_{friction} = F_f = 11$ N

$F_n = F_n = 18$ N

Unknown:

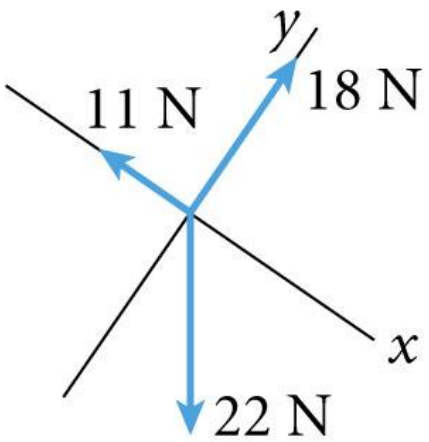
$F_{net} = ?$

Sample problem (continued)

2. Select a coordinate system & apply it to the free-body diagram.

Choose the *x*-axis parallel to and the *y*-axis perpendicular to the incline of the table, as shown in **(a)**

- This coordinate system is the most convenient
  - only one force needs to be resolved into *x* and *y* components.



(a)

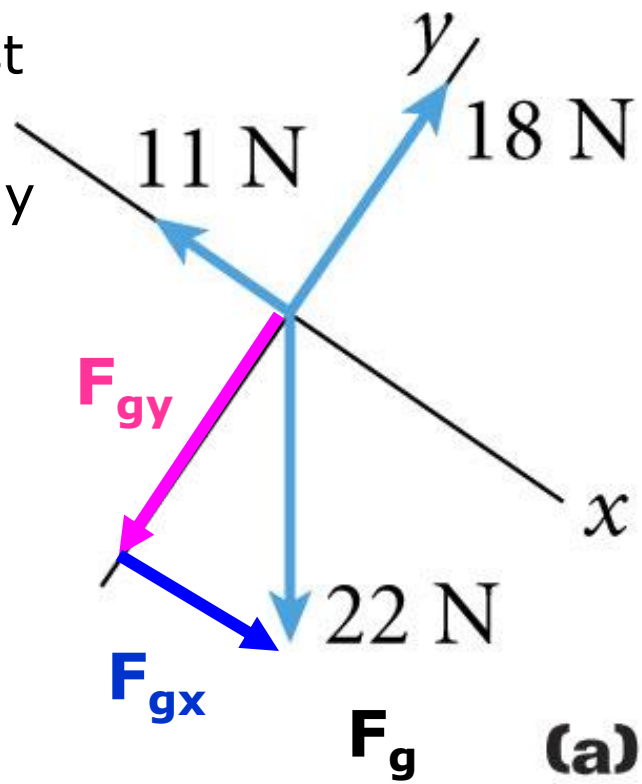
Tip: *To simplify the problem, always choose the coordinate system in which as many forces as possible lie on the x- and y-axes.*

Sample problem (continued)

3. Find the *x* and *y* components of all vectors.

Any vectors not on the x & y axis must be broken into its x & y components

- **F_g** must be broken up into Fgx & Fgy
  - The angle of the incline was 35°
  - Indicate angle is also 35°



$$F_{gy} = F_g \cos\theta$$

$$= (22N) \cos 35^o$$

$$F_{gy} = 18N$$

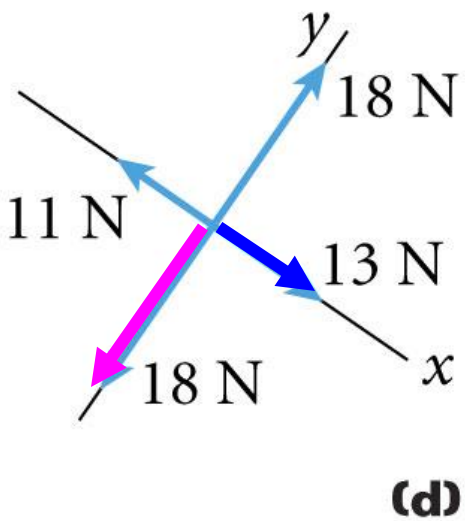
$$F_{gx} = F_g \sin\theta$$

$$= (22N) \sin 35^o$$

$$F_{gx} = 13N$$

Sample problem (continued)

4. Find the net force in both the *x* and *y* directions.
   - Show all the forces Diagram acting only along the *x*- and *y*-axes.



For the *x* direction:

$\Sigma F_x = F_{gx} - F_f$

$\Sigma F_x = 13\text{ N} - 11\text{ N}$

$\Sigma F_x = 2\text{ N}$

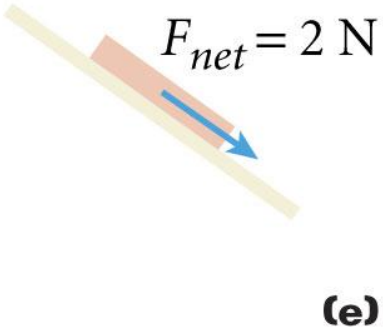
For the *y* direction:

$\Sigma F_y = F_n - F_{gy}$

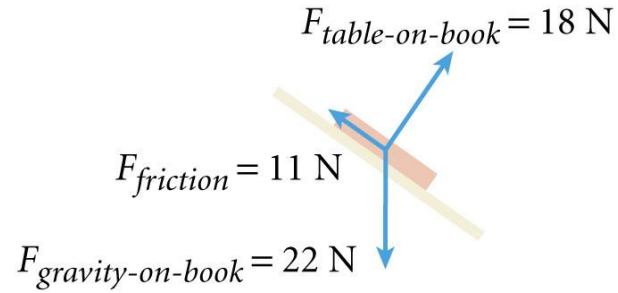
$\Sigma F_y = 18\text{ N} - 18\text{ N}$

$\Sigma F_y = 0\text{ N}$

5. Find the net force.



Friction



- Friction – is the force that opposes motion between 2 surfaces that are in contact

- In free-body diagrams, the force of friction is always **parallel** to the surface of contact.

- Force of friction (F_f) is proportional to the magnitude of the normal force (F_N)
  - F_f is always acts in a direction to oppose motion
    - Depends upon
      - Kinds of materials
      - How much they are pressed together

Types of Friction

1. Object is not moving

- **Static friction (F_s)** is a force that resists the start of sliding motion between two surfaces that are in contact and at rest

- As long as object doesn't move $F_s = - F_{applied}$

- Maximum force of F_s is $F_{s,max}$
  - $F_{s,Max}$ – Just before movement starts
  - $F_{s,max} = \mu_s F_N$
  - μ_s = coefficient of static friction
    - μ_s depends upon the two surfaces

Types of Friction (cont)

2. Object is moving

- **Kinetic friction** (F_k) is the force that opposes the movement of two surfaces that are in contact and are sliding over each other.
  - Kinetic friction is always less than the maximum static friction.
  - $F_k = \mu_k F_N$
    - μ_k = coefficient of kinetic friction

- For any pair of surfaces $\mu_k < \mu_s$
  - Its harder to push an object from rest than its is to keep it in motion

Coefficients of Friction Table

Coefficients of Friction

	μ_s	μ_k		μ_s	μ_k
Steel on steel	0.74	0.57	Waxed wood on wet snow	0.14	0.1
Aluminum on steel	0.61	0.47	Waxed wood on dry snow	—	0.04
Rubber on dry concrete	1.0	0.8	Metal on metal (lubricated)	0.15	0.06
Rubber on wet concrete	—	0.5	Ice on ice	0.1	0.03
Wood on wood	0.4	0.2	Teflon on Teflon	0.04	0.04
Glass on glass	0.9	0.4	Synovial joints in humans	0.01	0.003

Sample problem-Friction

Student attaches a rope to a 20.0 kg box of books. He pulls with a force of 90.0 N at an angle of 30.0° with the horizontal. The coefficient of kinetic friction between the box and the sidewalk is 0.500. Find the acceleration of the box.

Given:

m = 20.0 kg

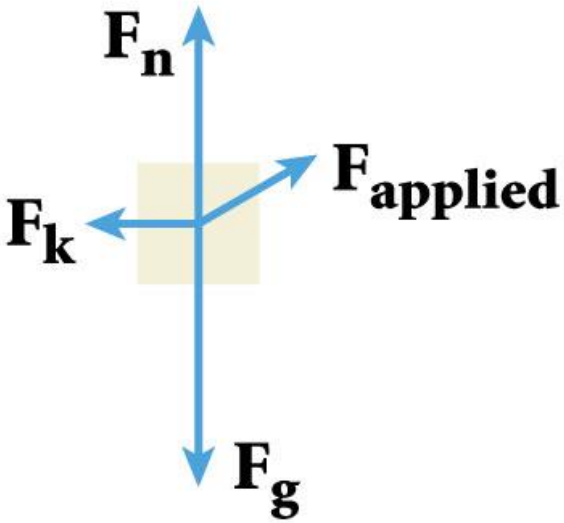
μ_k = 0.500

$F_{applied}$ = 90.0 N

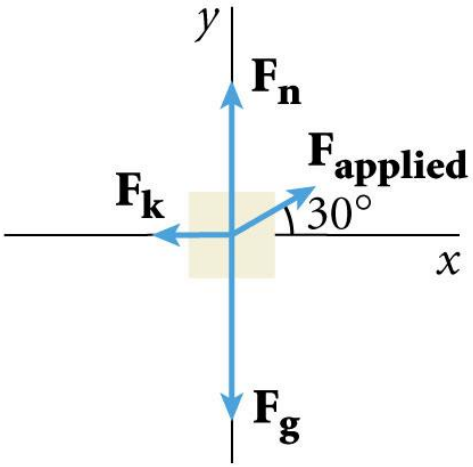
Angle = 30.0°

Unknown:

a = ?



Sample problem-Friction



- Any vectors not on X & Y axis break it into its components

$F_{ax} = F_a \cos\theta$

$F_{ax} = (90.0\ N)\cos 30.0^o$

$= 77.9\ N$

$F_{ay} = Fa \sin\theta$

$F_{ay} = (90.0\ N)\sin 30.0^o$

$= 45.0\ N$

<u>Sum of Forces in X-Direction</u>

$\Sigma F_x = ma_x$

$F_{ax} - F_k = ma$

$F_k = U_k F_n$ Sub into eqn

$F_{ax} - U_k F_n = ma$

<u>Sum of Forces in Y-Direction</u>

$\Sigma F_y = m\cancel{a_y}$ no motion in y

$F_{ay} - F_g + F_n = 0$

$F_n = F_g - F_{ay}$ $F_g = Mg$

$F_n = Mg - F_{ay}$

$F_n = (20.0\ kg)(9.81\ m/s^2) - 45.0\ N$

$F_n = 151\ N$

Sample problem-Friction

$F_{ax} - U_k F_n = ma_x$

$$a_x = \frac{F_{applied,x} - F_k}{m} = \frac{77.9\ \text{N} - 75.5\ \text{N}}{20.0\ \text{kg}} = \frac{2.4\ \text{N}}{20.0\ \text{kg}} = \frac{2.4\ \text{kg} \bullet \text{m/s}^2}{20.0\ \text{kg}}$$

a = 0.12 m/s^2 to the right