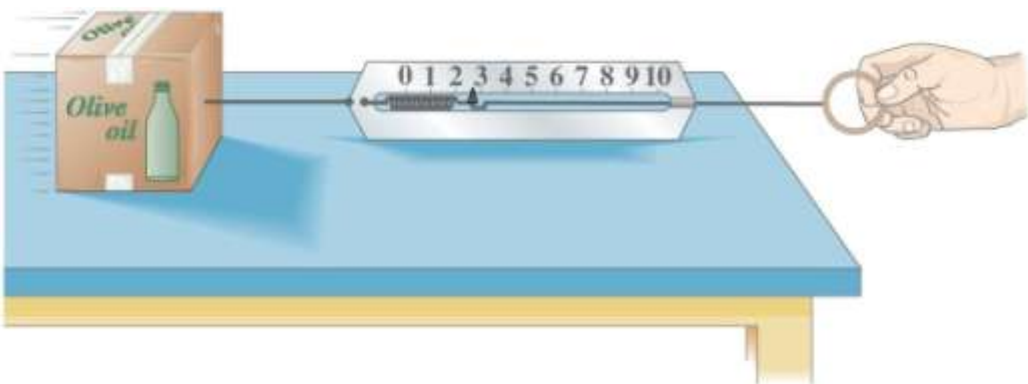
Chapter 4

Dynamics: Newton's Laws of Motion

4-1 Force

A **force** is a **push** or **pull**. An object at rest needs a force to get it **moving**; a moving object needs a force to change its **velocity**.

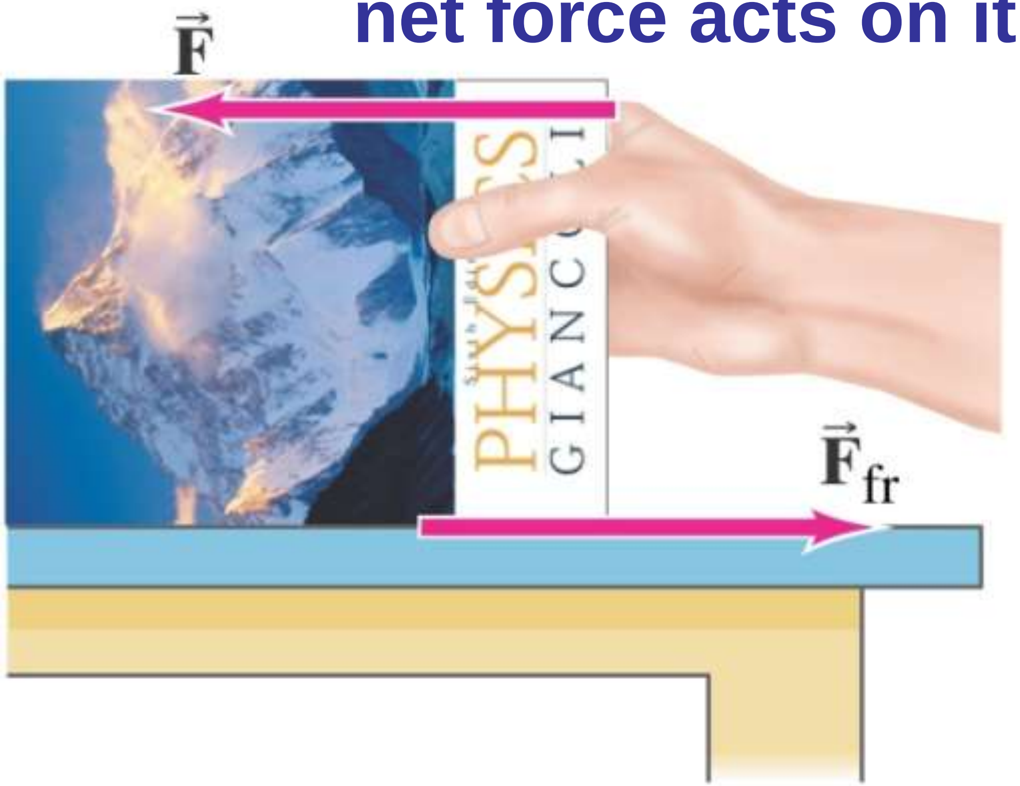


The **magnitude** of a force can be measured using a spring scale.

4-2 Newton’s First Law of Motion

Newton’s **first law** is often called the law of **inertia**.

Every object continues in its state of rest, or of uniform velocity in a straight line, as long as no net force acts on it.



4-2 Newton's First Law of Motion

Inertial reference frames:

An inertial reference frame is one in which Newton's first law is valid.

This excludes rotating and accelerating frames.

Newton’s First Law of Motion

Forces are Balanced

Objects at Rest

($v = 0$ m/s)

$a = 0$ m/s^2

Stay at Rest

Objects in Motion

($v \neq 0$ m/s)

$a = 0$ m/s^2

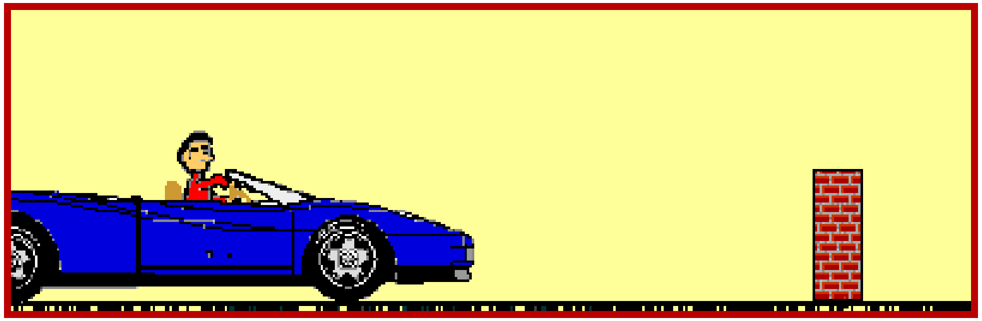
Stay in Motion

(same speed and dir'n)

Newton's First Law of Motion

A person in motion tends to stay in motion with the same speed and in the same direction ... unless <u>acted upon by the unbalanced force</u> of a seat belt.

The seat belt provides the unbalanced force which brings you from a state of motion to a state of rest.



Newton's First Law of Motion

Newton’s First Law of Motion

EXAMPLES

•blood rushes from your head to your feet when riding on a descending elevator which suddenly stops.

•the head of a hammer can be tightened onto the wooden handle by banging the bottom of the handle against a hard surface.

Newton's First Law of Motion

EXAMPLES

- to dislodge ketchup from the bottom of a ketchup bottle, the bottle is often turned upside down, thrust downward at a high speed and then abruptly halted.

- headrests are placed in cars to prevent whiplash injuries during rear-end collisions.

4-3 Mass

Mass is the measure of inertia of an object. In the SI system, mass is measured in **kilograms**.

Mass is not **weight**:

Mass is a **property** of an object. Weight is the **force** exerted on that object by gravity.

If you go to the moon, whose gravitational acceleration is about 1/6 *g*, you will weigh much less. Your mass, however, will be the same.

4-4 Newton's Second Law of Motion

Newton's **second law** is the relation between **acceleration** and **force**. Acceleration is proportional to force and inversely proportional to mass.

$$\Sigma \vec{\mathbf{F}} = m\vec{\mathbf{a}} \qquad \textbf{(4-1)}$$

4-4 Newton's Second Law of Motion

Force is a **vector**, so $\sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$ is true along each coordinate axis.

TABLE 4–1
Units for Mass and Force

System	Mass	Force
SI	kilogram (kg)	newton (N) $(= \mathrm{kg \cdot m/s^2})$
cgs	gram (g)	dyne $(= \mathrm{g \cdot cm/s^2})$
British	slug	pound (lb)

Conversion factors: 1 dyne $= 10^{-5}$ N; 1 lb $\approx$ 4.45 N.

The unit of force in the SI system is the **newton** (N).

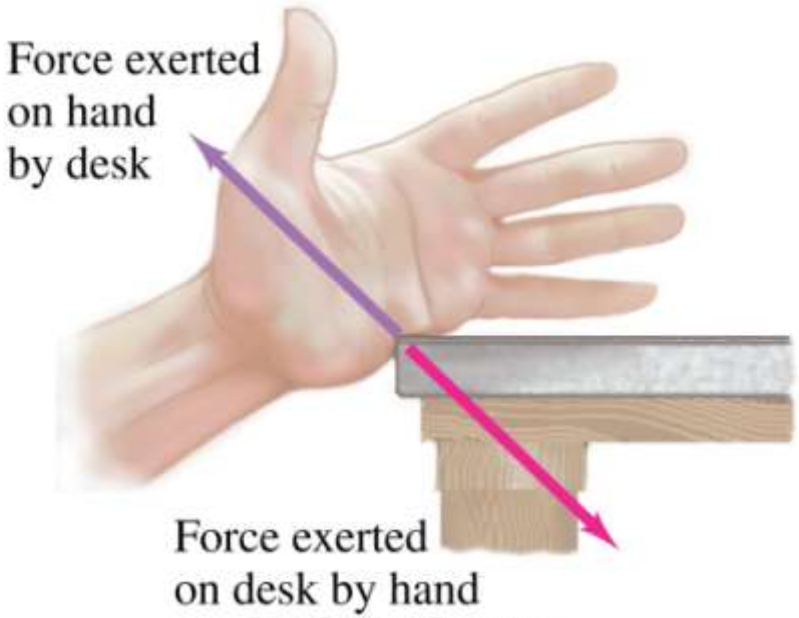
Note that the **pound** is a unit of **force**, not of mass, and can therefore be equated to newtons but not to kilograms.

4-5 Newton's Third Law of Motion

Any time a **force** is exerted on an object, that force is caused by another object.

Newton's **third law**:

Whenever one object exerts a **force** on a second object, the second exerts an equal force in the **opposite direction** on the first.



4-5 Newton's Third Law of Motion

A key to the correct application of the third law is that ***the forces are exerted on different objects***. Make sure you don't use them as if they were acting on the ***same*** object.

4-5 Newton’s Third Law of Motion

Rocket propulsion can also be explained using Newton’s third law: hot gases from combustion spew out of the tail of the rocket at high speeds. The **reaction force** is what propels the rocket.

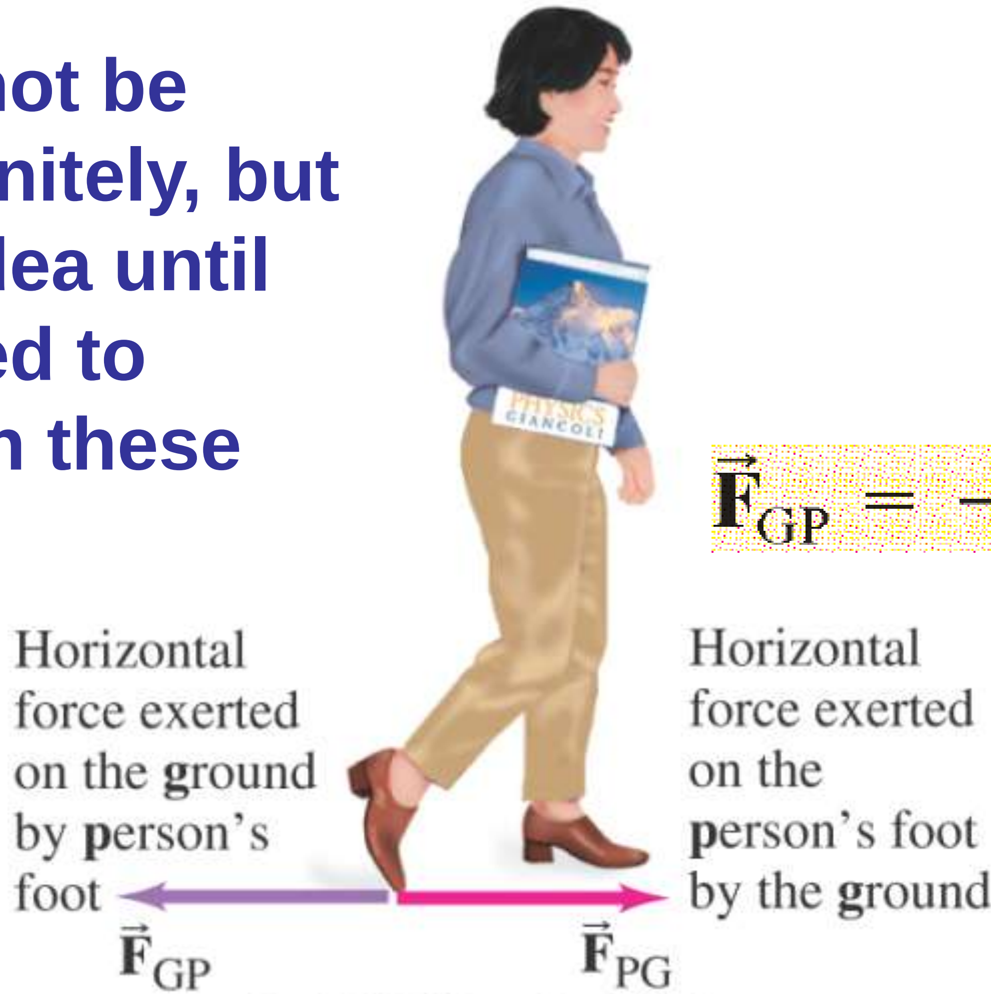
Note that the rocket does not need anything to “push” against.

4-5 Newton's Third Law of Motion

Helpful notation: the first **subscript** is the object that the force is being exerted on; the second is the source.

This need not be done indefinitely, but is a good idea until you get used to dealing with these forces.

$$\vec{\mathbf{F}}_{GP} = -\vec{\mathbf{F}}_{PG} \qquad (4\text{-}2)$$



4-6 Weight – the Force of Gravity; and the Normal Force

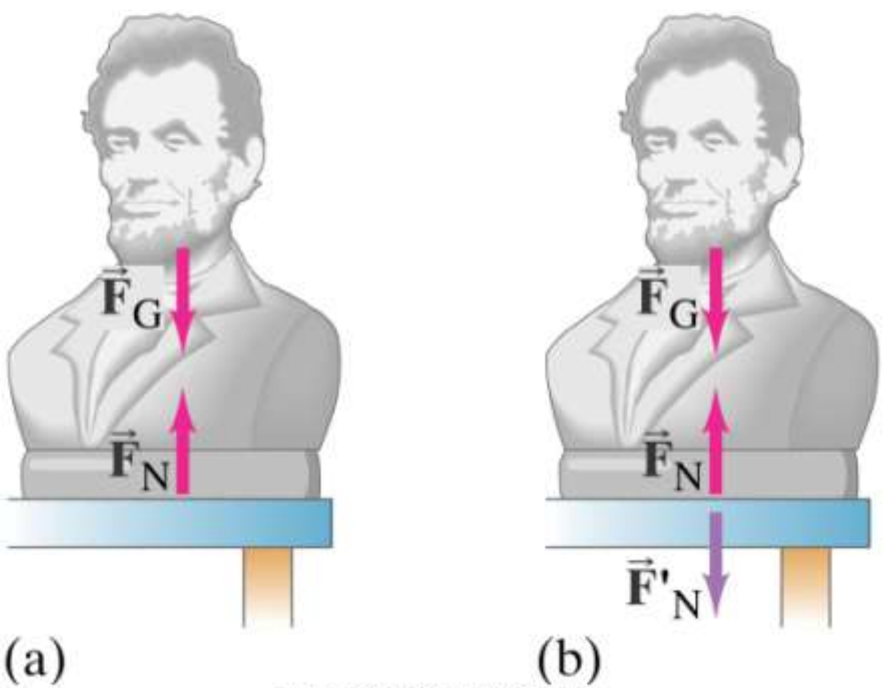
Weight is the force exerted on an object by gravity. Close to the surface of the Earth, where the gravitational force is nearly constant, the weight is:

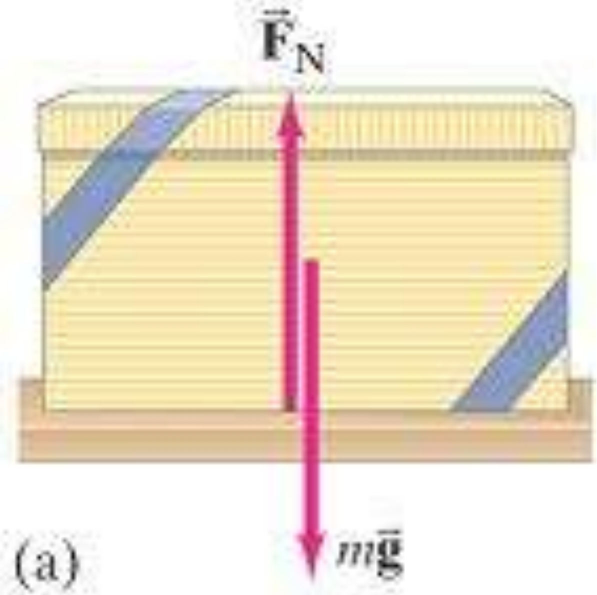
$$\vec{\mathbf{F}}_G = m\vec{\mathbf{g}}$$

4-6 Weight – the Force of Gravity; and the Normal Force

An object at rest must have no **net force** on it. If it is sitting on a table, the force of gravity is still there; what other force is there?

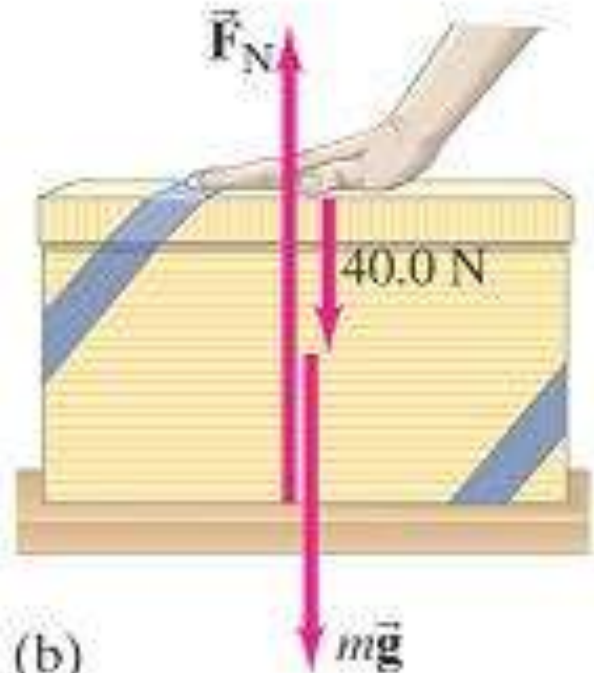
The force exerted perpendicular to a surface is called the **normal force**. It is exactly as large as needed to balance the force from the object (if the required force gets too big, something breaks!)





(a)

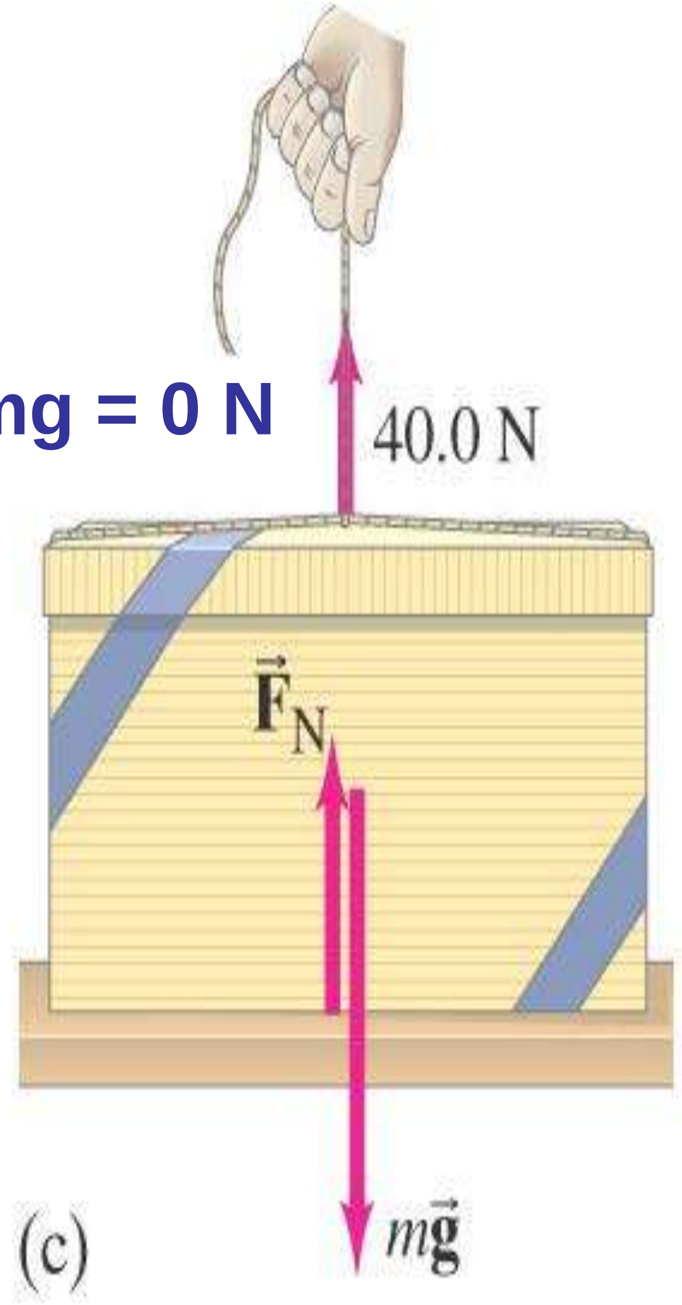
$$\Sigma F = F_N - mg = 0\ N$$

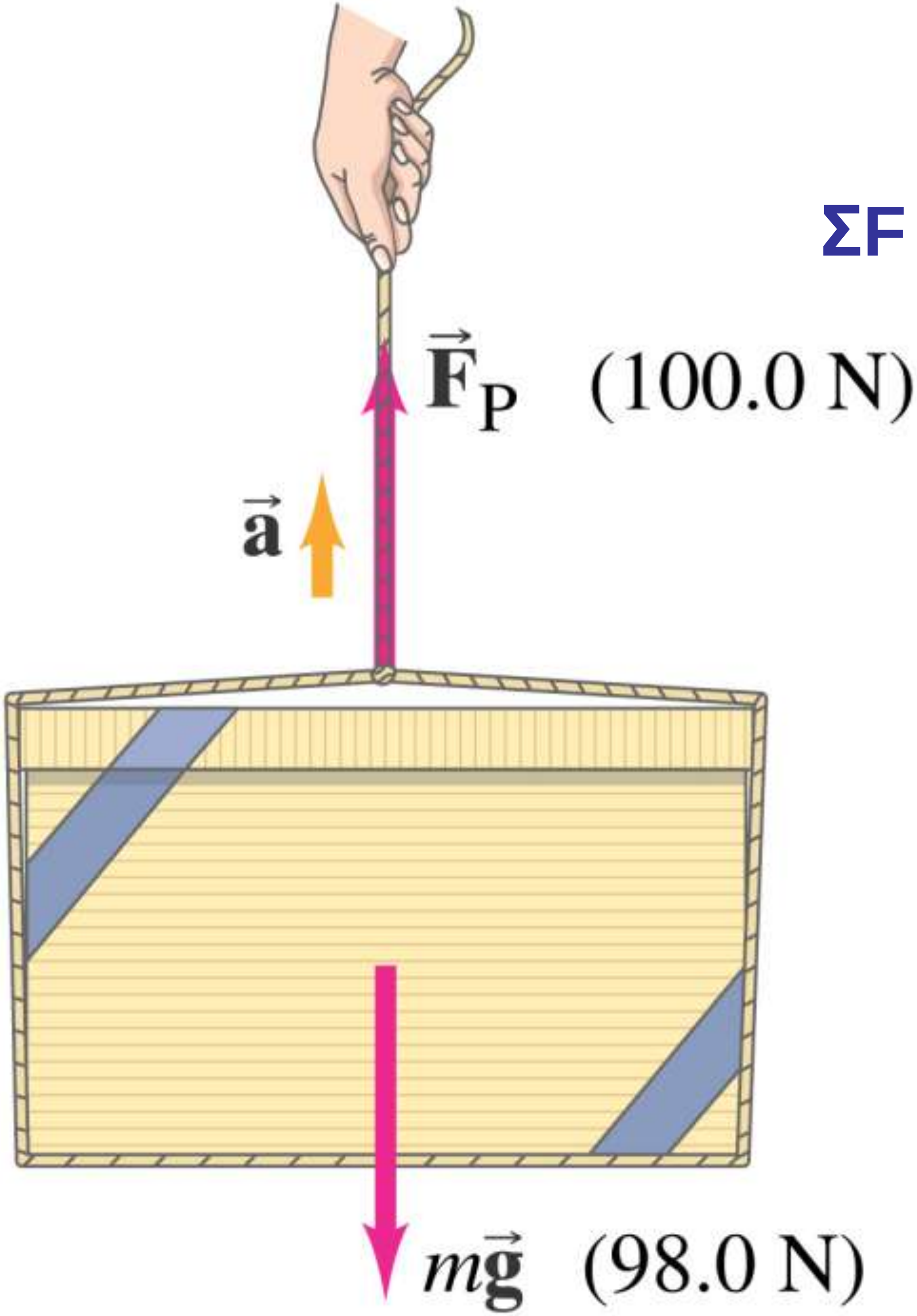


(b)

$$\Sigma F = F_N - mg - 40\ N = 0\ N$$

$$\Sigma F = F_N + 40\ N - mg = 0\ N$$





$\Sigma F = F_P - mg = 2\ N$

The box accelerates upward because $F_P > mg$.

1. While driving, Anna Litical observed a bug striking the windshield of her car. Obviously, a case of Newton's third law of motion. The bug hit the windshield and the windshield hit the bug. Which of the two forces is greater: the force on the bug or the force on the windshield?

2. Rockets are unable to accelerate in space because ...

a. there is no air in space for the rockets to push off of.

b. there is no gravity is in space.

c. there is no air resistance in space.

d. Nonsense! Rockets do accelerate in space.

3. A gun recoils when it is fired. The recoil is the result of action-reaction force pairs. As the gases from the gunpowder explosion expand, the gun pushes the bullet forwards and the bullet pushes the gun backwards.

The acceleration of the recoiling gun is ...

a. greater than the acceleration of the bullet.

b. smaller than the acceleration of the bullet.

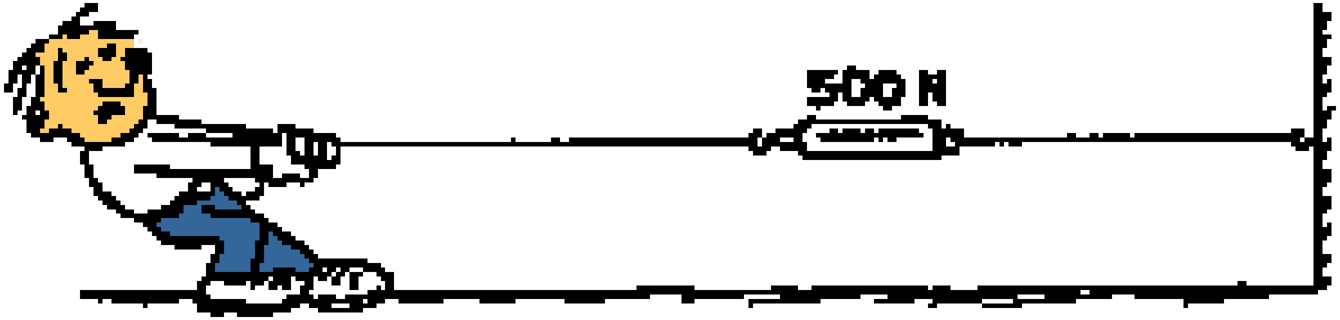
c. the same size as the acceleration of the bullet.

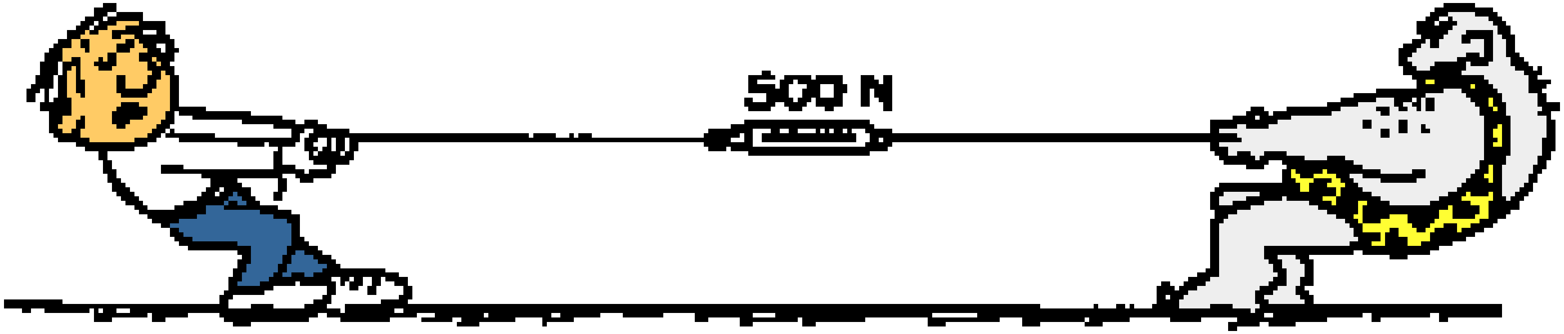
4. A physics student is pulling upon a rope which is attached to a wall. In the bottom picture, the physics student is pulling upon a rope which is held by the Strongman. In each case, the force scale reads 500 Newtons. The physics student is pulling...

a. with more force when the rope is attached to the wall.

b. with more force when the rope is attached to the Strongman.

c.

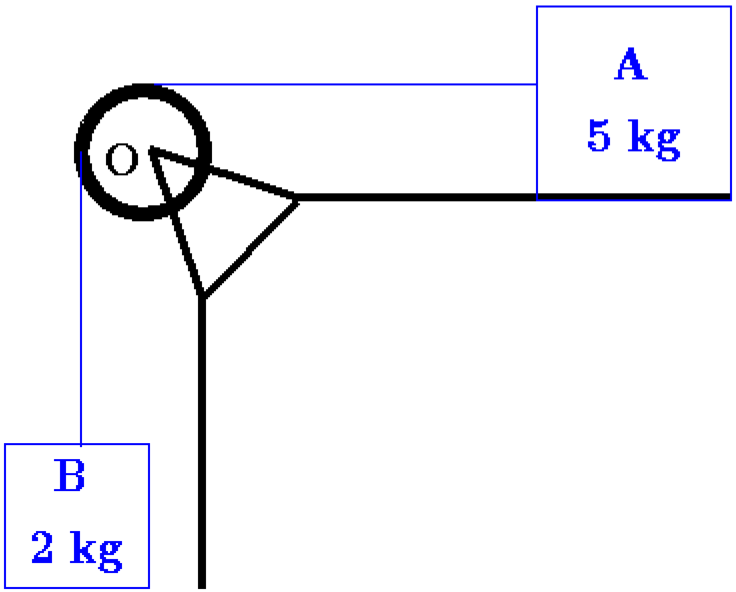




Free Body Diagrams

1.Identify **the object(s) of interest**

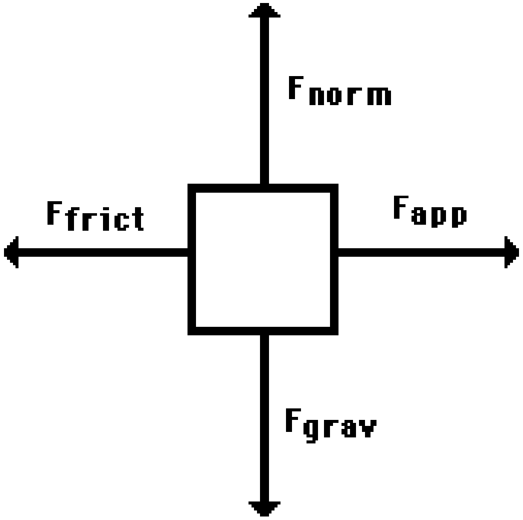
2.Draw **a separate free body diagram** ***for each object***



Free Body Diagrams

***3. For each diagram,* do the following:**

- ***a.** Draw* **all forces on the free body as vectors coming out of the object**



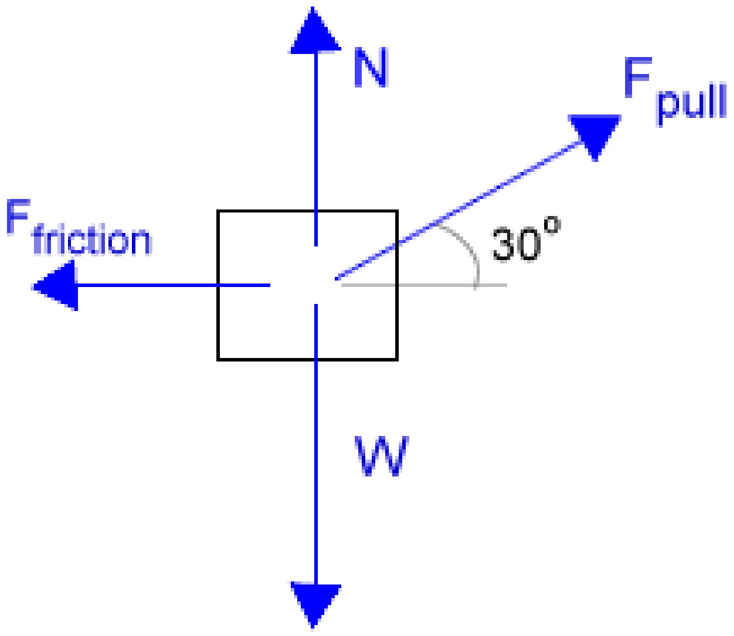
- ***b.** Draw* **all other information (velocity, acceleration, etc.)** ***away from the object***

Free Body Diagrams

***3. For each diagram,* do the following:**

c. *Label* an appropriate coordinate axis

d. *Identify* and *Label* the x- and y- components of all forces



Free Body Diagrams

3. For each diagram, **do the following:**

e. *Write* Newton's Second Law in component form:

$$\Sigma F_x = ma_x$$

$$\Sigma F_y = ma_y$$

e. Find ΣF_x and ΣF_y from the *diagram*

f. Find ma_x and ma_y from your *knowledge* of the problem

Free Body Diagrams

Notes to Remember:

1. Pay attention to *sign conventions*, based on your choice of axes

2. Only draw *forces* on the object itself, not velocities or accelerations

Free Body Diagrams

Notes to Remember:

3. Only draw forces that act *on* the object

4. Any object "at rest" or "at constant velocity" in any dimension (x or y) has that component of its acceleration (a_x or a_y) equal to zero

5. *Normal* means "perpendicular to a surface". There is a normal force *only* if an object is *against a surface*, and it always points *away* from that surface

Free Body Diagrams

Notes to Remember:

6. ***Tension*** **exists** ***only*** **if there is a rope/string pulling on an object. Tension always points** ***along*** **the rope/string, and it is** ***the same at both ends.***
   (this is important if you have a rope attached to two objects, as in a pulley problem)

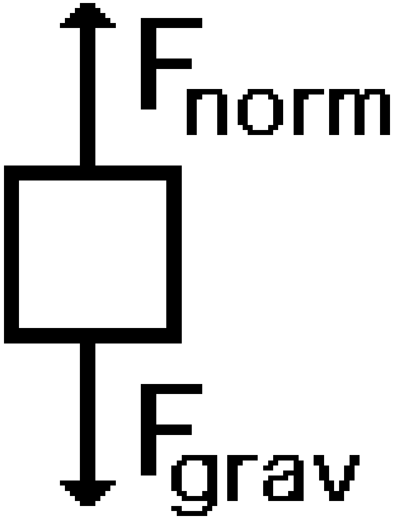
7. **The** ***centripetal force*** **is** ***not*** **an extra force on the diagram. It is just a** ***name*** **for the net force in the center-pointing direction.**

Free Body Diagrams

Test your Knowledge

Draw a FBD for the following situation

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

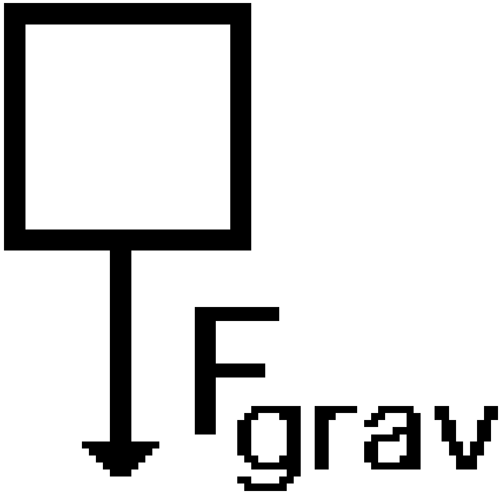


Free Body Diagrams

Test your Knowledge

Draw a FBD for the following situation

3. An egg is free-falling from a nest in a tree. Neglect air resistance. Diagram the forces acting on the egg as it falls.

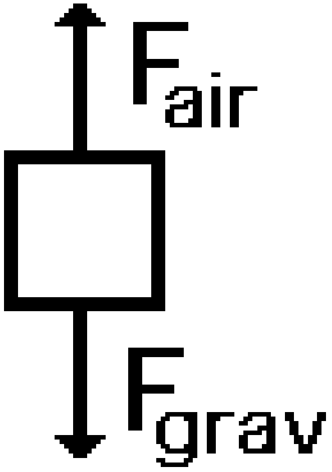


Free Body Diagrams

Test your Knowledge

Draw a FBD for the following situation

4. A flying squirrel is gliding (no wing flaps) from a tree to the ground at constant velocity. Consider air resistance. Diagram the forces acting on the squirrel.

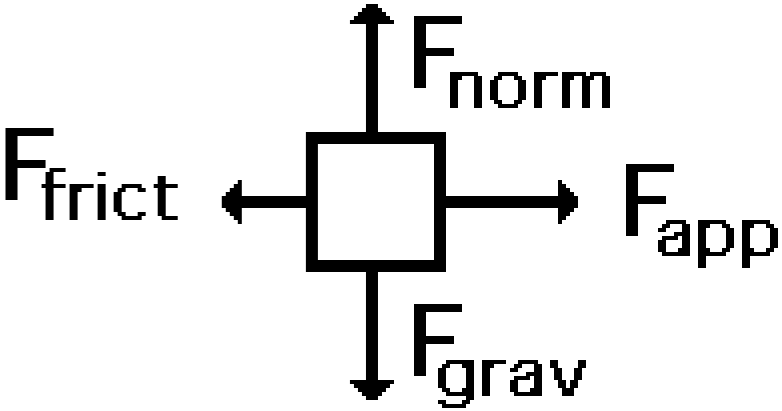


Free Body Diagrams

Test your Knowledge

Draw a FBD for the following situation

5. A rightward force is applied to a book in order to move it across a desk with a rightward acceleration. Consider frictional forces. Neglect air resistance. Diagram the forces acting on the book.

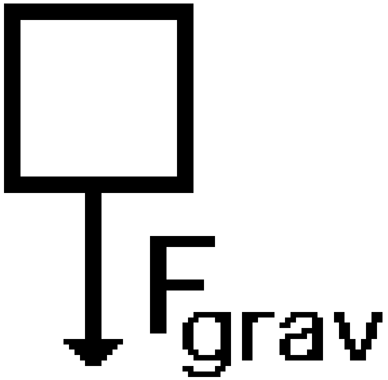


Free Body Diagrams

Test your Knowledge

Draw a FBD for the following situation

6. A football is moving upwards towards its peak after having been booted by the punter. Neglect air resistance. Diagram the forces acting upon the football as it rises upward towards its peak.

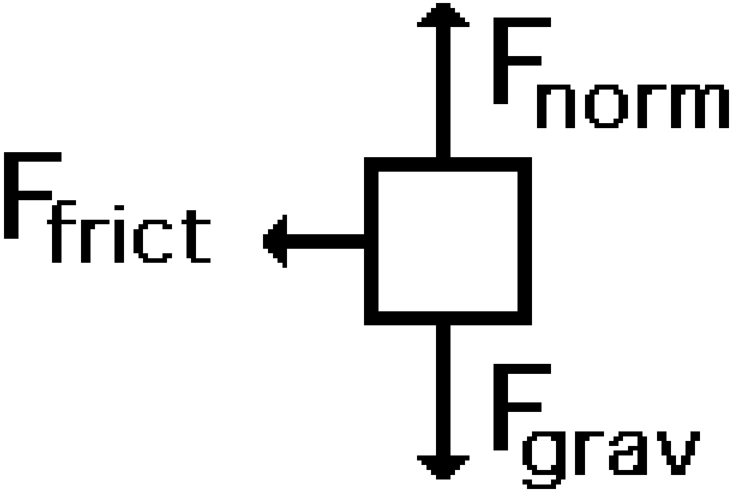


Free Body Diagrams

Test your Knowledge

Draw a FBD for the following situation

7. A car is coasting to the right and slowing down. Diagram the forces acting upon the car.

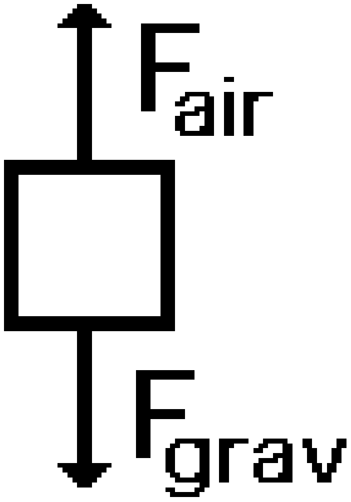


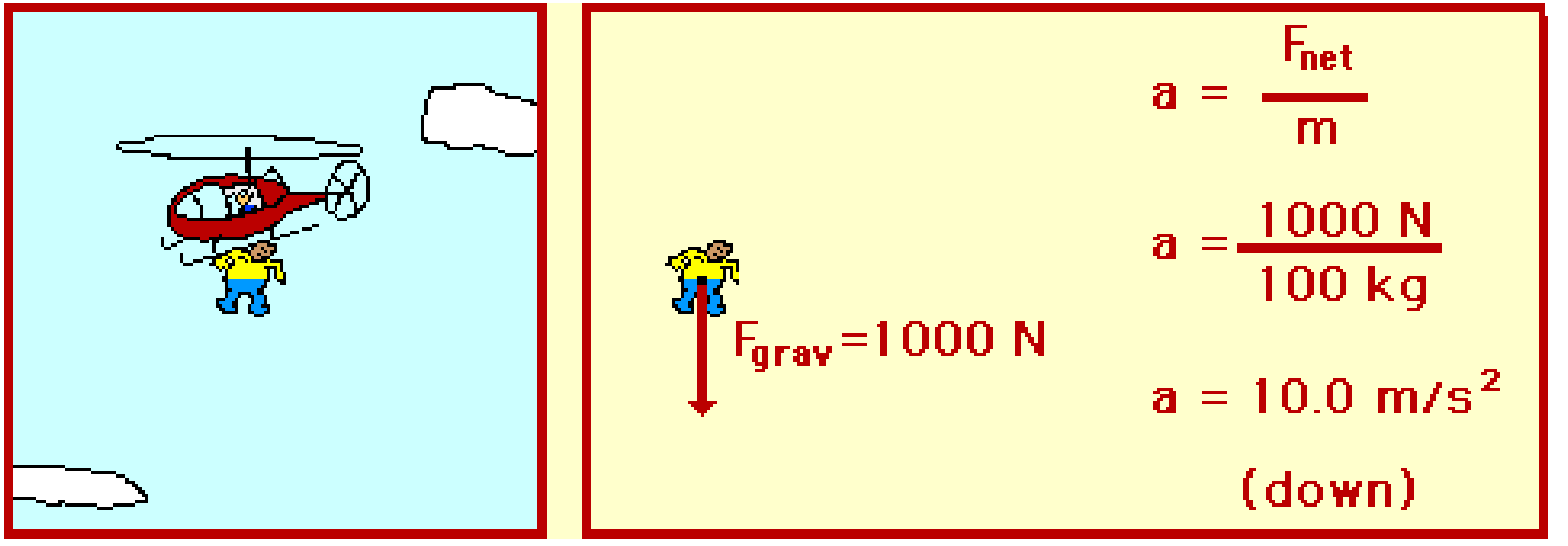
Free Body Diagrams

Test your Knowledge

Draw a FBD for the following situation

8. A skydiver is descending with a constant velocity. Consider air resistance. Diagram the forces acting upon the skydiver.





A typical skydiver reaches terminal velocity of 55 m/s in 6 seconds.

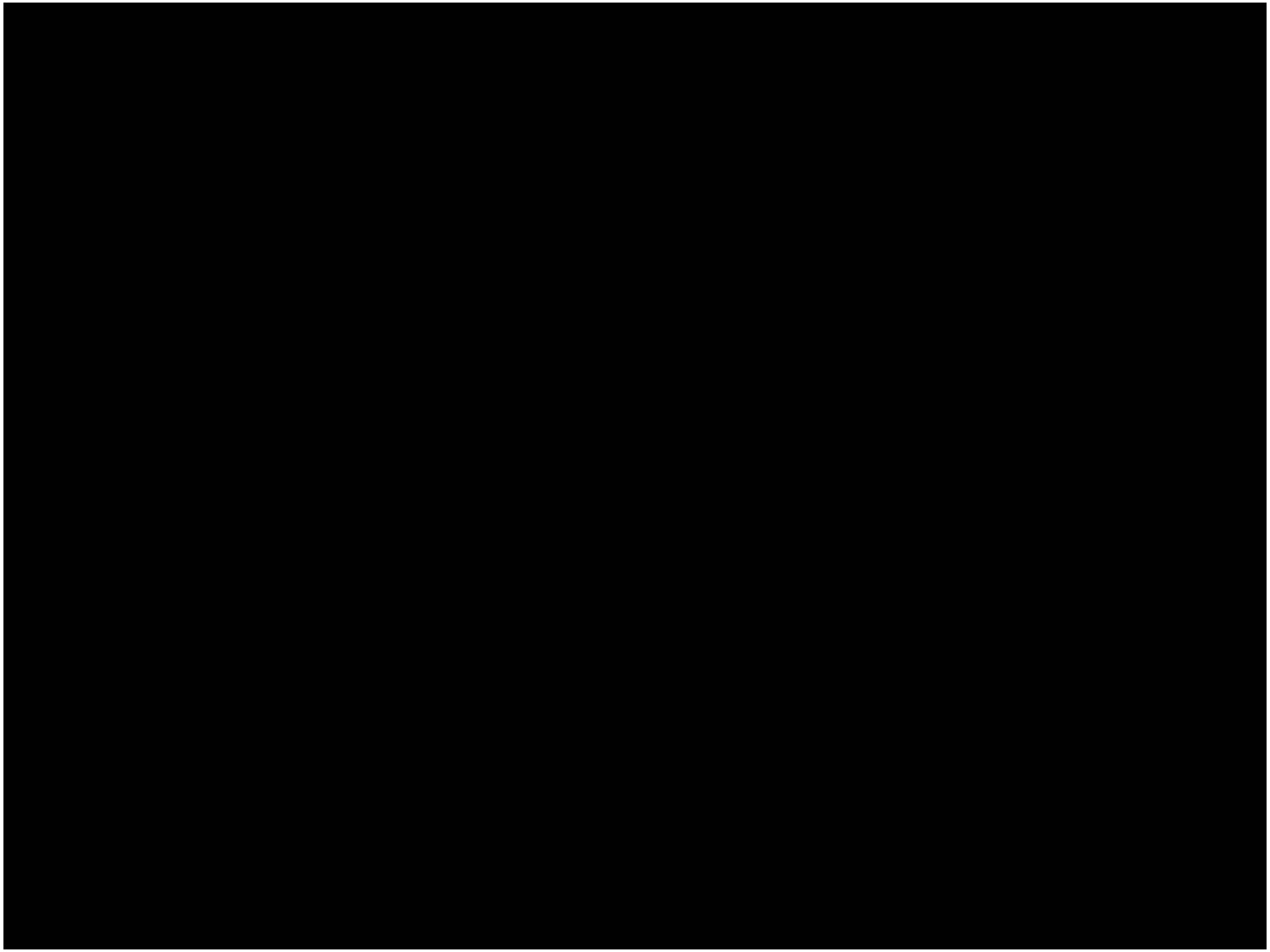
World Record Skydive

Joseph Kittinger jumped 102,800 feet (31,333 meters) in Excelsior III balloon August 16, 1960

He experienced air temperatures as low as minus 94 degrees Fahrenheit (minus 70 degrees Celsius)

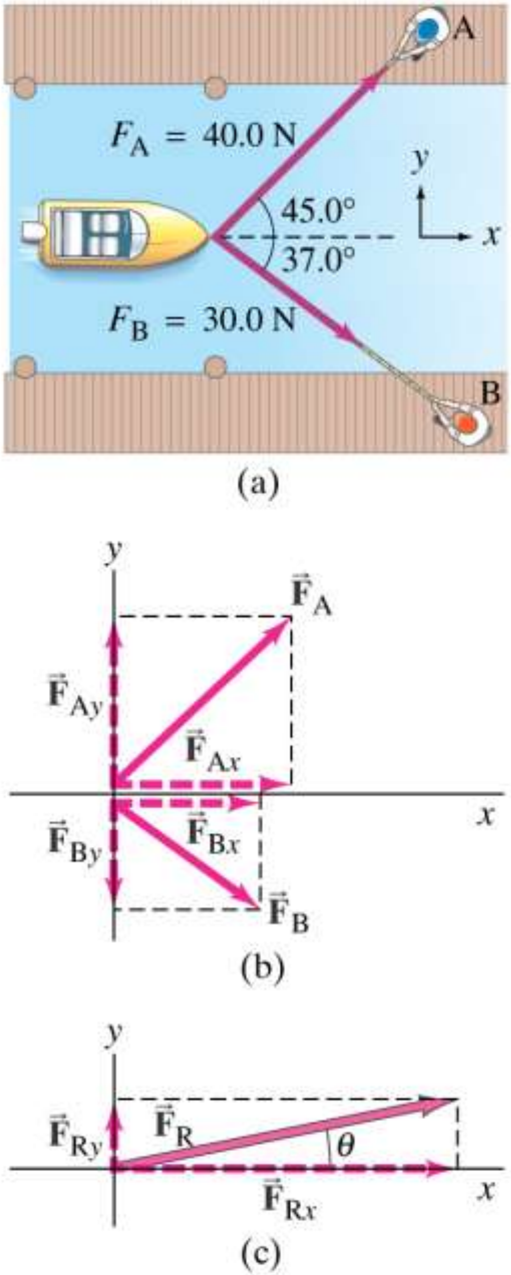
Only four minutes and 36 seconds more were needed to bring him down to about 17,500 feet (5,334 meters) where his regular 28-foot (8.5-meter) parachute opened, allowing him to float the rest of the way to Earth.


[Joseph Kittinger movie]



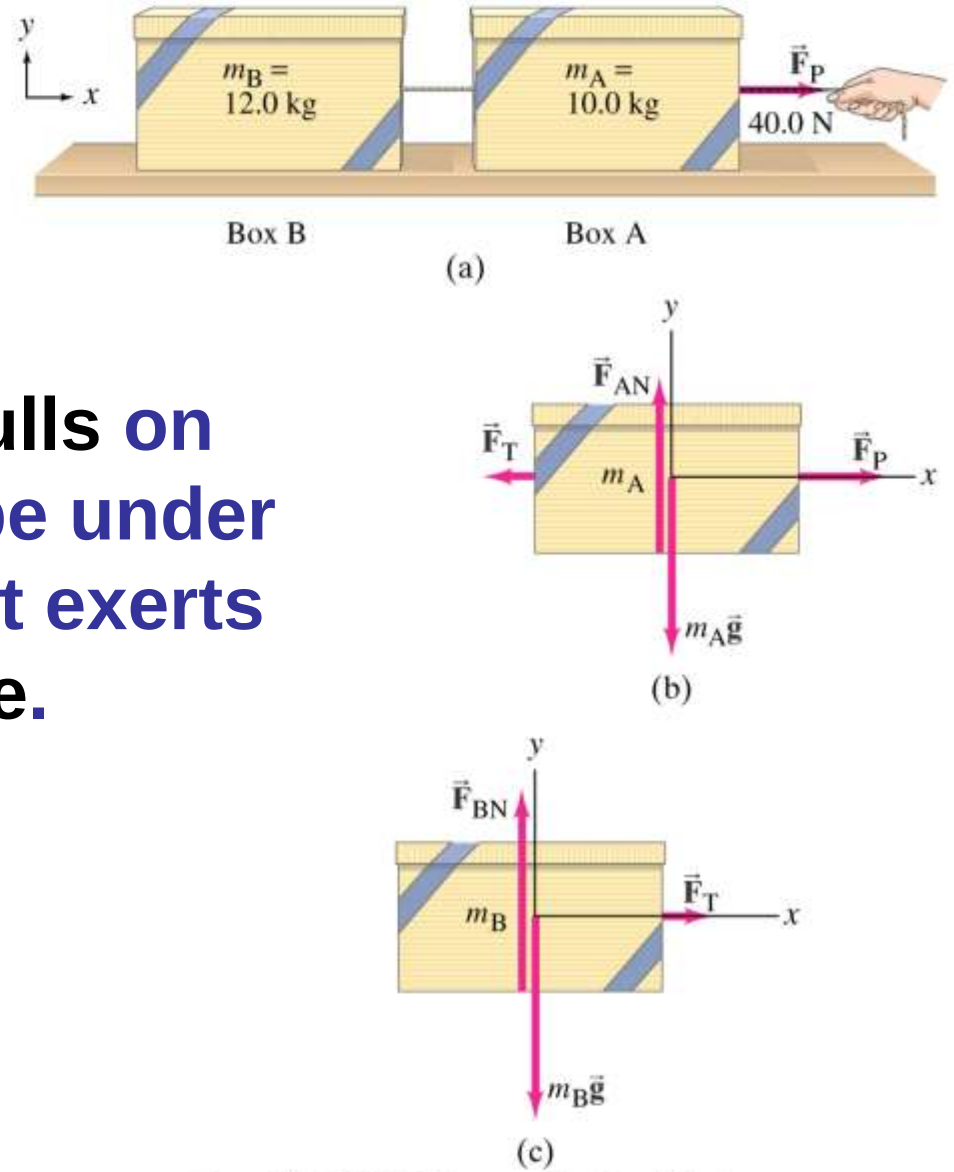
Skyventure- skydiving without the height

4-7 Solving Problems with Newton's Laws – Free-Body Diagrams



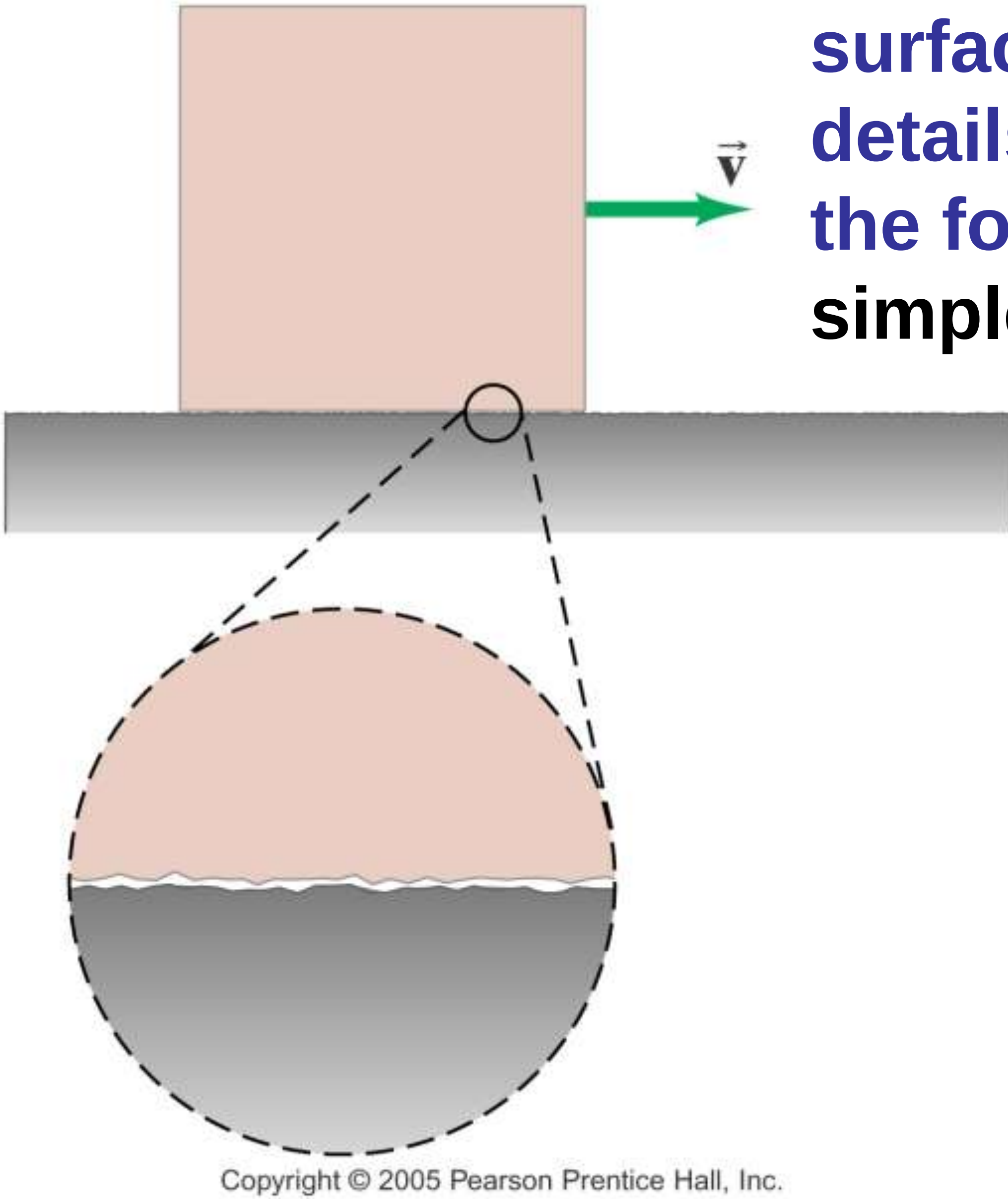
1. Draw a **sketch**.
2. For one object, draw a **free-body diagram**, showing all the forces acting *on* the object. Make the **magnitudes** and **directions** as accurate as you can. **Label** each force. If there are multiple objects, draw a separate diagram for each one.
3. **Resolve** vectors into components.
4. Apply Newton's **second law** to each component.
5. Solve.

4-7 Solving Problems with Newton’s Laws – Free-Body Diagrams



When a cord or rope **pulls** on an object, it is said to be under **tension**, and the force it exerts is called a **tension force**.

4-8 Applications Involving Friction, Inclines



On a **microscopic** scale, most surfaces are rough. The exact details are not yet known, but the force can be modeled in a **simple** way.

For **kinetic** – sliding – friction, we write:

$$F_{\mathrm{fr}} = \mu_{\mathrm{k}} F_{\mathrm{N}}$$

μ_{k} is the coefficient of **kinetic** friction, and is different for every pair of surfaces.

4-8 Applications Involving Friction, Inclines

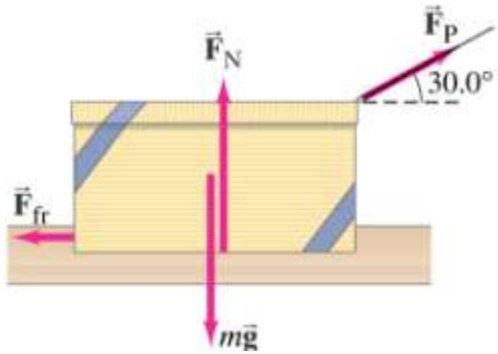


TABLE 4–2 Coefficients of Friction[†]

Surfaces	Coefficient of Static Friction, μ_s	Coefficient of Kinetic Friction, μ_k
Wood on wood	0.4	0.2
Ice on ice	0.1	0.03
Metal on metal (lubricated)	0.15	0.07
Steel on steel (unlubricated)	0.7	0.6
Rubber on dry concrete	1.0	0.8
Rubber on wet concrete	0.7	0.5
Rubber on other solid surfaces	1–4	1
Teflon® on Teflon in air	0.04	0.04
Teflon on steel in air	0.04	0.04
Lubricated ball bearings	<0.01	<0.01
Synovial joints (in human limbs)	0.01	0.01

[†] Values are approximate and intended only as a guide.

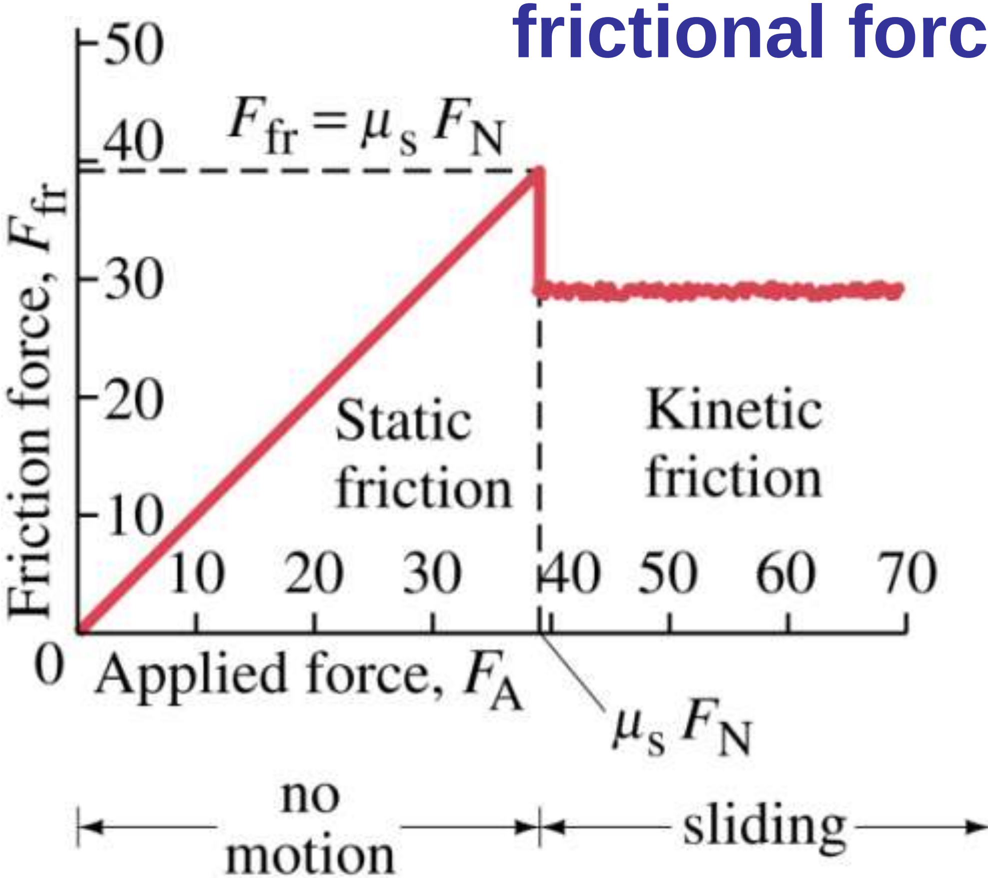
4-8 Applications Involving Friction, Inclines

Static friction is the frictional force between two surfaces that are **not** moving along each other. Static friction keeps objects on inclines from sliding, and keeps objects from moving when a force is first applied.

$$F_{\mathrm{fr}} \leq \mu_{\mathrm{s}} F_{\mathrm{N}}$$

4-8 Applications Involving Friction, Inclines

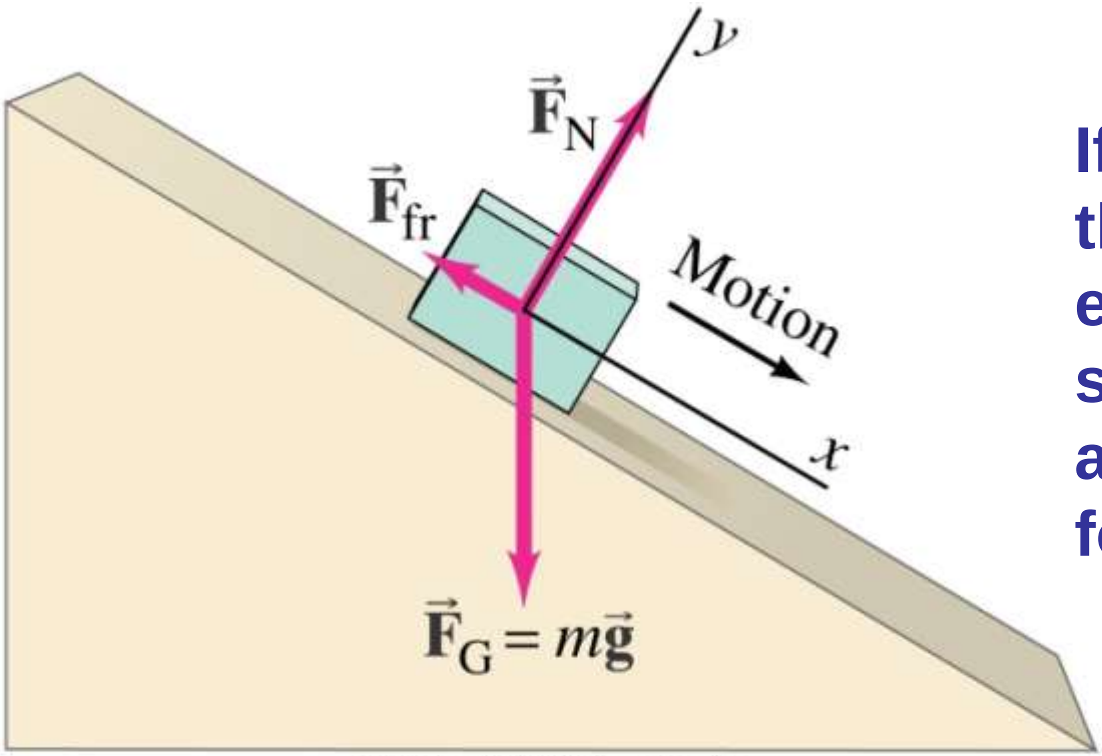
The static frictional force **increases** as the applied force increases, until it reaches its **maximum**. Then the object starts to move, and the **kinetic** frictional force takes over.



4-8 Applications Involving Friction, Inclines

An object sliding down an incline has three forces acting on it: the normal force, gravity, and the frictional force.

- The normal force is always perpendicular to the surface.
- The friction force is parallel to it.
- The gravitational force points down.



If the object is at rest, the forces are the same except that we use the static frictional force, and the sum of the forces is zero.

4-9 Problem Solving – A General Approach

1. **Read** the problem carefully; then read it again.
2. **Draw** a sketch, and then a free-body diagram.
3. Choose a convenient **coordinate system**.
4. List the **known** and **unknown** quantities; find **relationships** between the knowns and the unknowns.
5. **Estimate** the answer.
6. Solve the problem without putting in any numbers (**algebraically**); once you are satisfied, put the **numbers** in.
7. Keep track of **dimensions**.
8. Make sure your answer is **reasonable**.

Summary of Chapter 4

- **Newton's first law: If the net force on an object is zero, it will remain either at rest or moving in a straight line at constant speed.**
- **Newton's second law:** $\Sigma\vec{\mathbf{F}} = m\vec{\mathbf{a}}$
- **Newton's third law:** $\vec{\mathbf{F}}_{\mathrm{AB}} = -\vec{\mathbf{F}}_{\mathrm{BA}}$
- **Weight is the gravitational force on an object.**
- **The frictional force can be written:** $F_{\mathrm{fr}} = \mu_{\mathrm{k}} F_{\mathrm{N}}$

(kinetic friction) or $F_{\mathrm{fr}} \leq \mu_{\mathrm{s}} F_{\mathrm{N}}$ **(static friction)**

- **Free-body diagrams are essential for problem-solving**