PHYS 1441 – Section 001
Lecture #6

Thursday, June 5, 2008

Dr. Jaehoon Yu

- Newton's third law of motion
- Types of Forces
- The Gravitational Force
  - Newton's Law of Universal Gravitation
  - Weight
- The Normal Force
- Static and Kinetic Friction Forces
- The Tension Force
- Equilibrium Applications of Newton's Laws of Motion

Today's homework is homework #4, due 9pm, Monday, June 9!!

Announcements

- E-mail Distribution list
  – 43 out of 47 registered as of this morning!!
- Quiz next Monday, June 9
  – Covers: CH4.4 – what we learn today
- Problems # 1- 4 in HW#3 have been deleted since they were not covered in the class yet
- Supplemental Instructor, Dr. Satyanand, offers additional help for homework and class material as follow:
  – Time: Mondays and Thursdays, 12:00 – 2PM
  – Location: SH125
- Second term exam
  – 8 – 10am, Tuesday, June 17, in SH103
  – Covers CH4.1 – What we finish next Thursday, June 12
  – Practice test will be posted on the class web page
    - No answer keys will be posted
  – Dr. Satyanand will conduct a help session 8 – 10am, Monday, June 16 in class

Reminder: Special Project for Extra Credit

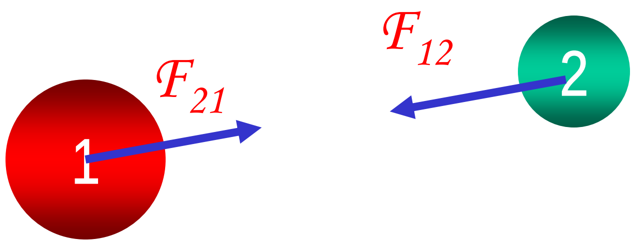
- Show that a projectile motion's trajectory is a parabola!!
  - 20 points
  - Due: Monday, June 9
  - You MUST show full details of computations to obtain any credit
    - Beyond what is included in this lecture!!

Special Project

- Using the fact that $g=9.80m/s^2$ on the Earth's surface, find the average density of the Earth
  - Use only the values of the constant of universal gravitation and the radius of the Earth, in addition to the value of the gravitational acceleration g given in this problem
- 20 point extra credit
- Due: Thursday, June 12
- You must show your OWN, detailed work to obtain any credit!!

Newton's Third Law (Law of Action and Reaction)

If two objects interact, the force F_{21} exerted on object 1 by object 2 is equal in magnitude and opposite in direction to the force F_{12} exerted on object 2 by object 1.



$$\vec{F}_{12} = -\vec{F}_{21}$$

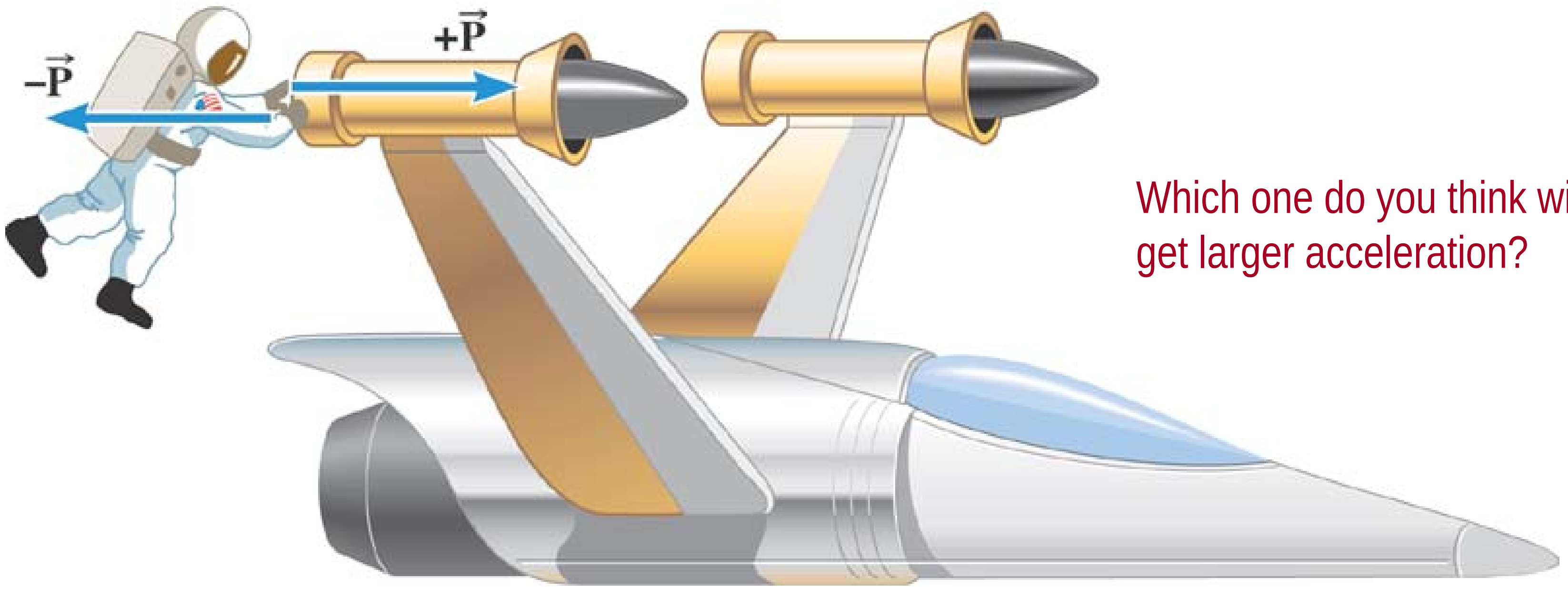
*The action force is equal in magnitude to the reaction force but in opposite direction. These two forces always act **on different objects**.*

What is the reaction force to the force of a free falling object?

The gravitational force exerted by the object to the Earth!

Stationary objects on top of a table has a reaction force (called the normal force) from table to balance the action force, the gravitational force.

Ex. 4 The Accelerations Produced by Action and Reaction Forces



Which one do you think will get larger acceleration?

Suppose that the magnitude of the force is 36 N. If the mass of the spacecraft is 11,000 kg and the mass of the astronaut is 92 kg, what are the accelerations?

Ex. 4 continued

Force exerted on the space craft by the astronaut $\sum \vec{\mathbf{F}} = \vec{\mathbf{P}}.$

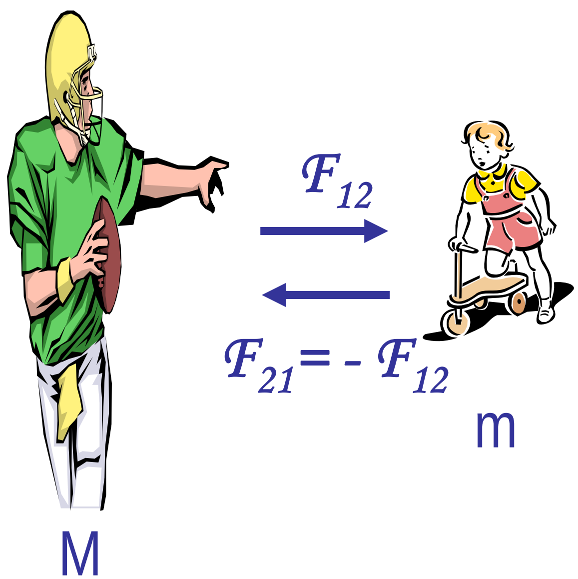
Force exerted on the astronaut by the space craft $\sum \vec{\mathbf{F}} = -\vec{\mathbf{P}}.$

space craft's acceleration $$\vec{\mathbf{a}}_s = \frac{\vec{\mathbf{P}}}{m_s} = \frac{+36\text{ N}}{11{,}000\text{ kg}} = +0.0033\,\text{m/s}^2$$

astronaut's acceleration $$\vec{\mathbf{a}}_A = \frac{-\vec{\mathbf{P}}}{m_A} = \frac{-36\text{ N}}{92\text{ kg}} = -0.39\,\text{m/s}^2$$

Example of Newton's 3rd Law

A large man and a small boy stand facing each other on frictionless ice. They put their hands together and push against each other so that they move apart. a) Who moves away with the higher speed and by how much?



$$\vec{F}_{12} = -\vec{F}_{21} \Rightarrow \left|\vec{F}_{12}\right| = \left|\vec{F}_{21}\right| = F$$

$$\vec{F}_{12} = m\vec{a}_b \Rightarrow \begin{aligned} F_{12x} &= ma_{bx} \\ F_{12y} &= ma_{by} = 0 \end{aligned}$$

$$\vec{F}_{21} = M\vec{a}_M \Rightarrow \begin{aligned} F_{21x} &= Ma_{Mx} \\ F_{21y} &= Ma_{My} = 0 \end{aligned}$$

Since $\vec{F}_{12} = -\vec{F}_{21}$ and $\left|\vec{F}_{12}\right| = \left|-\vec{F}_{21}\right| = F$

Establish the equation $\Rightarrow$ $ma_{bx} = F = Ma_{Mx}$ Divide by m $\Rightarrow$ $a_{bx} = \dfrac{F}{m} = \dfrac{M}{m} a_{Mx}$

Example of Newton's 3rd Law, cnt'd

Man's velocity

$$v_{Mxf} = v_{Mxi} + a_{Mx}t = a_{Mx}t$$

Boy's velocity

$$v_{bxf} = v_{bxi} + a_{bx}t = a_{bx}t = \frac{M}{m}a_{Mx}t = \frac{M}{m}v_{Mxf}$$

So boy's velocity is higher than man's, if M>m, by the ratio of the masses.

b) Who moves farther while their hands are in contact?

Boy's displacement

$$x_b = v_{bxi}t + \frac{1}{2}a_{bx}t^2 = \frac{M}{2m}a_{Mx}t^2$$

$$x_b = \frac{M}{m}\left(\frac{1}{2}a_{Mx}t^2\right) = \frac{M}{m}x_M$$

Man's displacement

Given in the same time interval, since the boy has higher acceleration and thereby higher speed, he moves farther than the man.

Types of Forces

- Fundamental Forces: Truly unique forces that cannot be derived from any other forces
  - Total of three fundamental forces
    - Gravitational Force
    - Electro-Weak Force
    - Strong Nuclear Force
- Non-fundamental forces: Forces that can be derived from fundamental forces
  - Friction
  - Tension in a rope
  - Normal or support forces

Newton's Law of Universal Gravitation

People have been very curious about the stars in the sky, making observations for a long time. The data people collected, however, have not been explained until Newton has discovered the law of gravitation.

Every particle in the Universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

How would you write this law mathematically?

$$F_g \propto \frac{m_1 m_2}{r_{12}^2} \quad \xrightarrow{\text{With } G} \quad F_g = G\frac{m_1 m_2}{r_{12}^2}$$

G is the universal gravitational constant, and its value is

$$G = 6.673 \times 10^{-11}$$

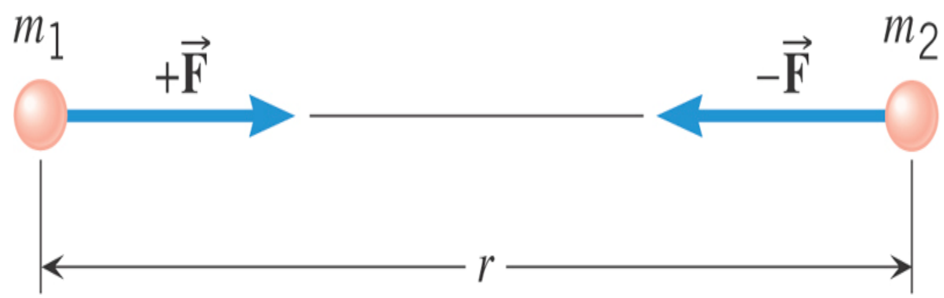
Unit? $N \cdot m^2 / kg^2$

This constant is not given by the theory but must be measured by experiments.

This form of forces is known as the inverse-square law, because the magnitude of the force is inversely proportional to the square of the distances between the objects.

Ex. 5. Gravitational Attraction

What is the magnitude of the gravitational force that acts on each particle in the figure, assuming m_1=12kg, m_2=25kg, and r=1.2m?

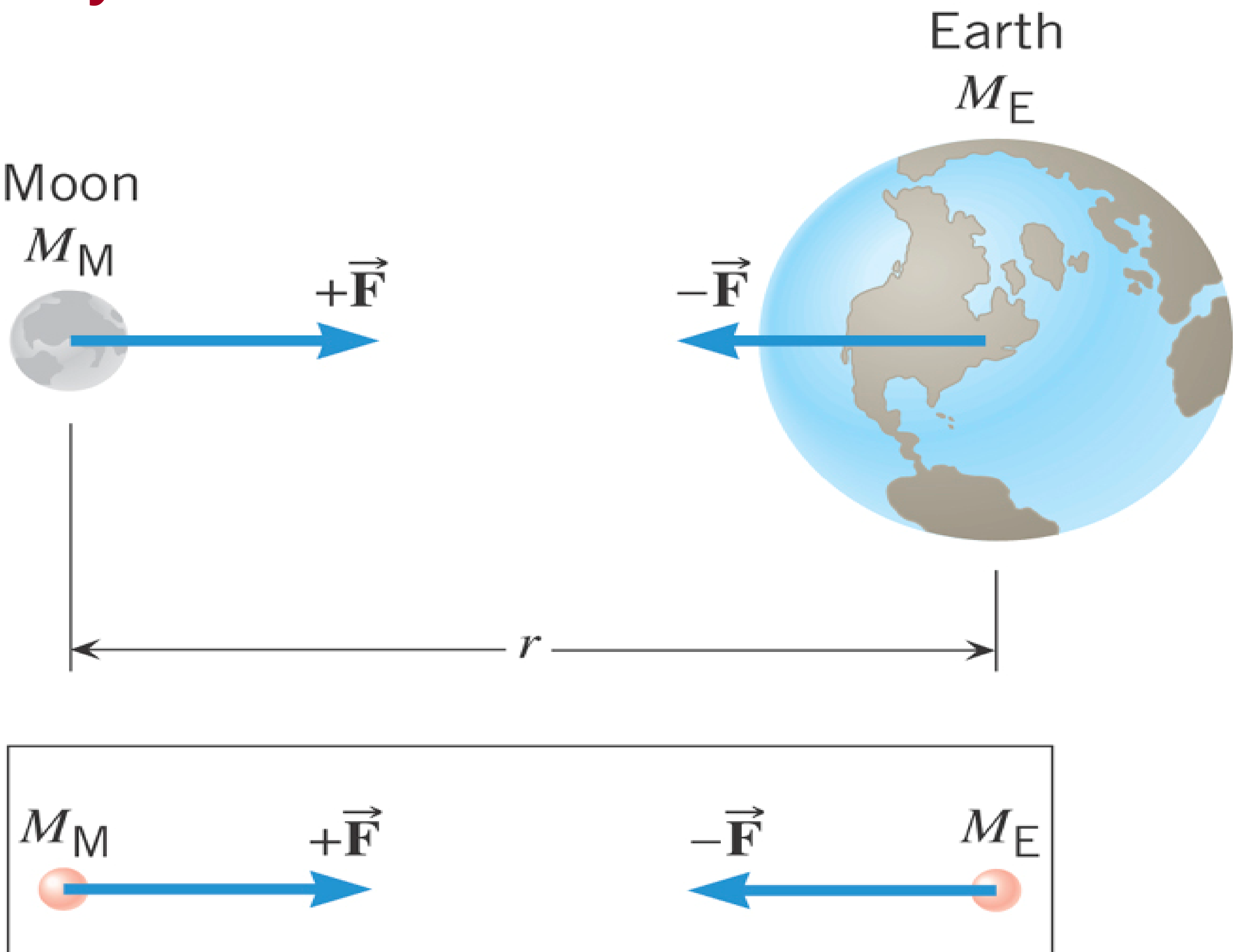


$$F = G\frac{m_1 m_2}{r^2}$$

$$= \left(6.67\times10^{-11}\ \mathrm{N\cdot m^2/kg^2}\right)\frac{(12\ \mathrm{kg})(25\ \mathrm{kg})}{(1.2\ \mathrm{m})^2}$$

$$= 1.4\times10^{-8}\ \mathrm{N}$$

Why does the Moon orbit the Earth?



Gravitational Force and Weight

Gravitational Force, $\mathcal{F}_g$

The attractive force exerted on an object by the Earth

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

Weight of an object with mass M is

$$W = \left|\vec{F}_G\right| = M\left|\vec{g}\right| = Mg$$

What is the SI unit of weight?

N

*Since weight depends on the magnitude of gravitational acceleration, **g**, it varies depending on geographical location.*

By measuring the forces one can determine masses. This is why you can measure mass using the spring scale.

Gravitational Acceleration

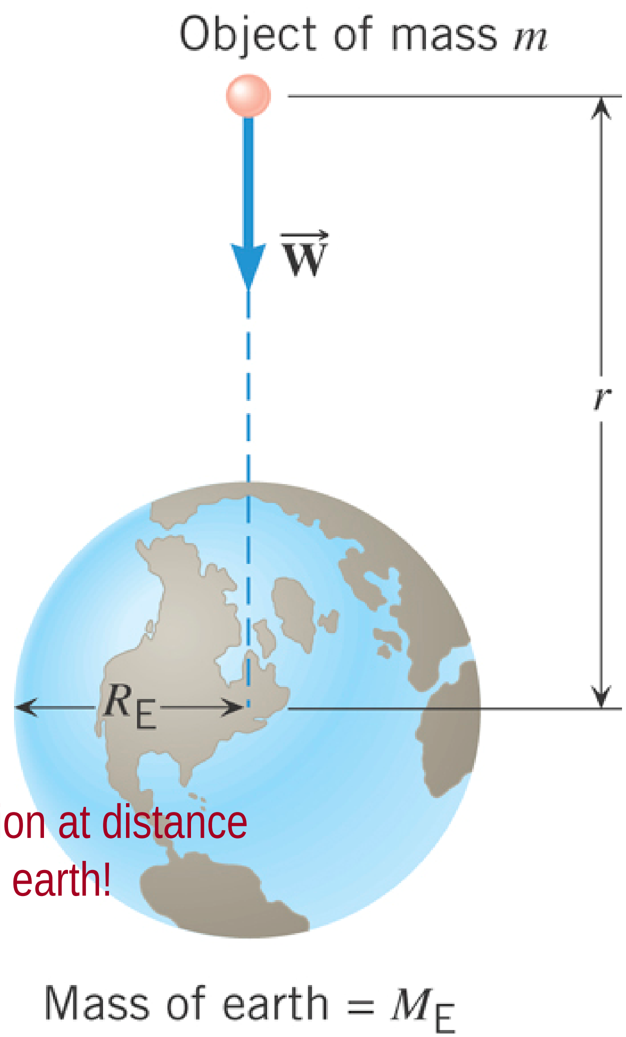
$$W = G\frac{M_E m}{r^2}$$

$$W = mg$$

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

$$g = G\frac{M_E}{r^2}$$

Gravitational acceleration at distance r from the center of the earth!



What is the SI unit of g? $\boxed{\mathrm{m/s^2}}$

Magnitude of the gravitational acceleration on the surface of the Earth

Gravitational force on the surface of the earth:

$$F_G = G\frac{M_E m}{r^2} = G\frac{M_E \cancel{m}}{R_E^2} = \cancel{m}g$$

$$g = G\frac{M_E}{R_E^2}$$

$G = 6.67\times10^{-11}\ \mathrm{N\cdot m^2/kg^2}$

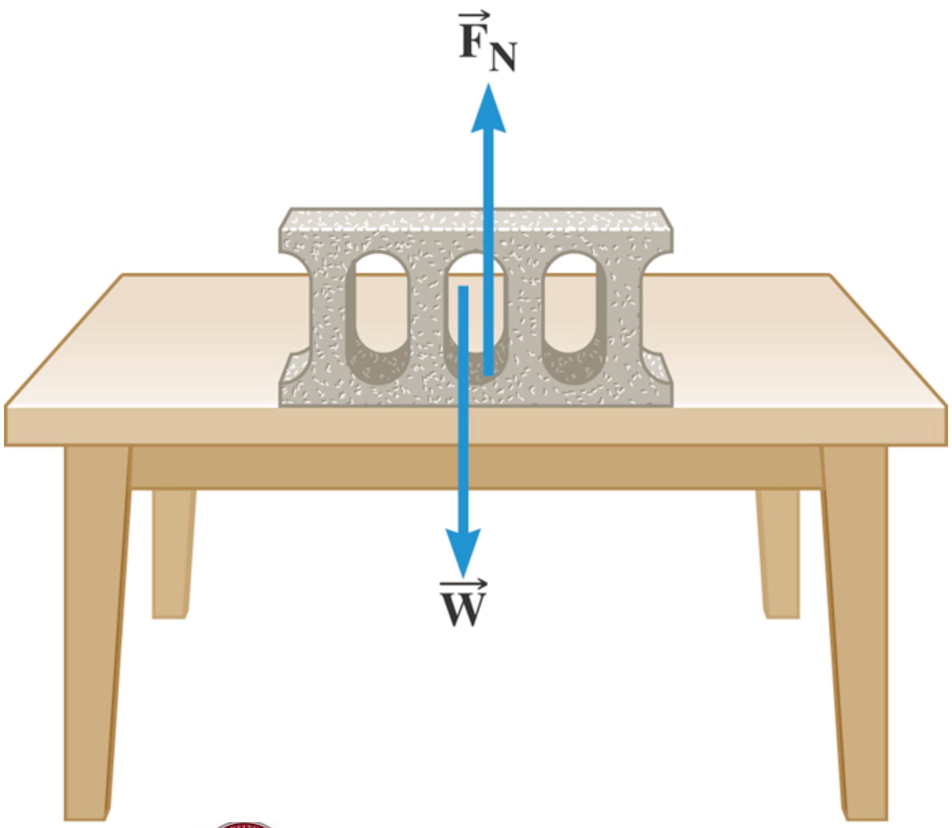
$M_E = 5.98\times10^{24}\ \mathrm{kg};\quad R_E = 6.38\times10^{6}\ m$

$$= \left(6.67\times10^{-11}\ \mathrm{N\cdot m^2/kg^2}\right)\frac{\left(5.98\times10^{24}\ \mathrm{kg}\right)}{\left(6.38\times10^{6}\ \mathrm{m}\right)^2}$$

$$= 9.80\ \mathrm{m/s^2}$$

The Normal Force

The normal force is one component of the forces that a surface exert on an object with which it is in contact – namely, the component that is always <u>perpendicular to the surface</u>.

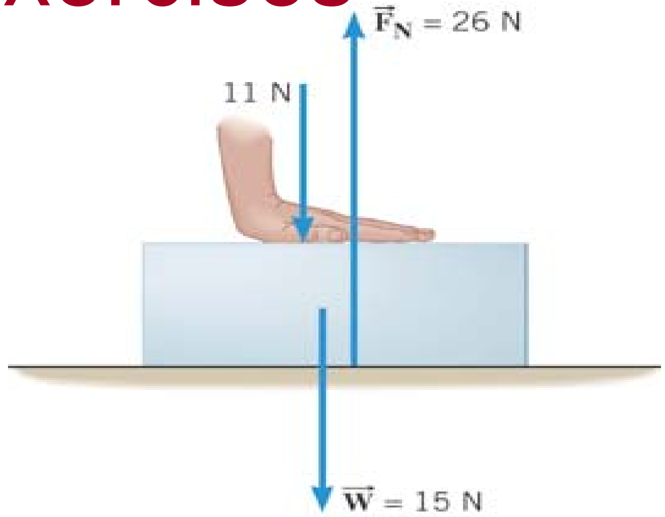


Some normal force exercises

Case 1: Hand pushing down on the book

$$F_N - 11\ \text{N} - 15\ \text{N} = 0$$

$$F_N = 26\ \text{N}$$

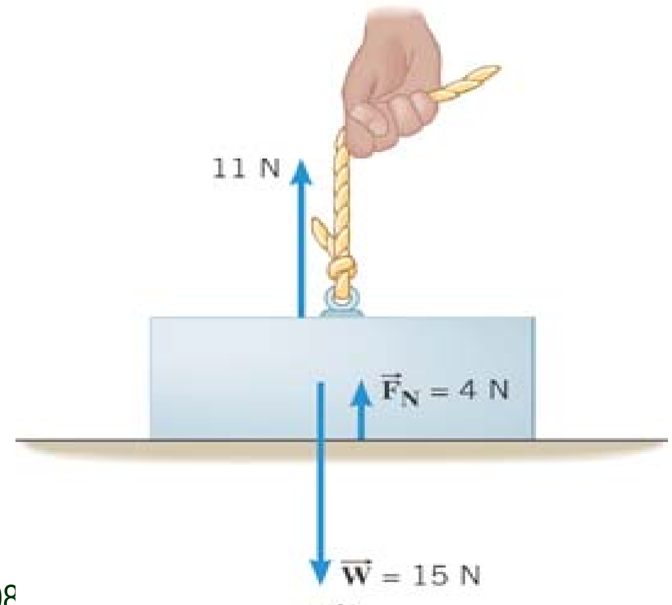


(a)

Case 2: Hand pulling up the book

$$F_N + 11\ \text{N} - 15\ \text{N} = 0$$

$$F_N = 4\ \text{N}$$

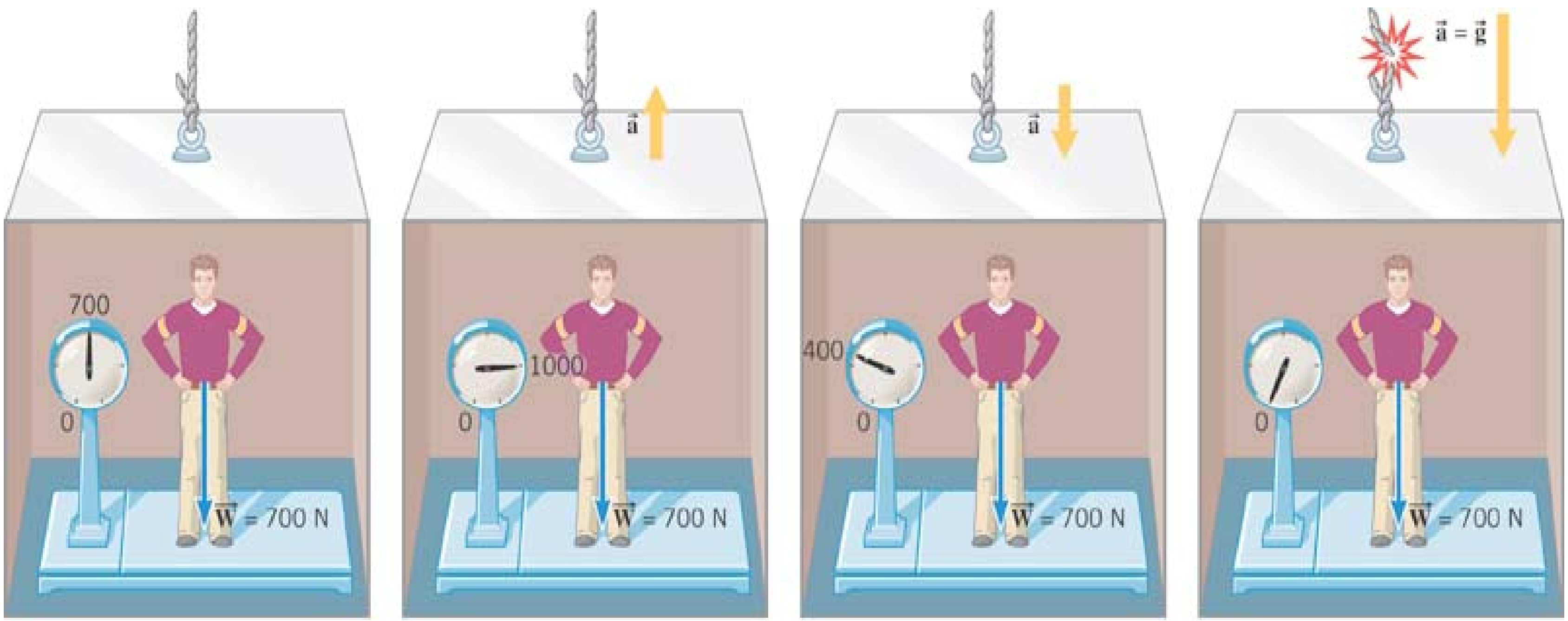


(b)

Apparent Weight

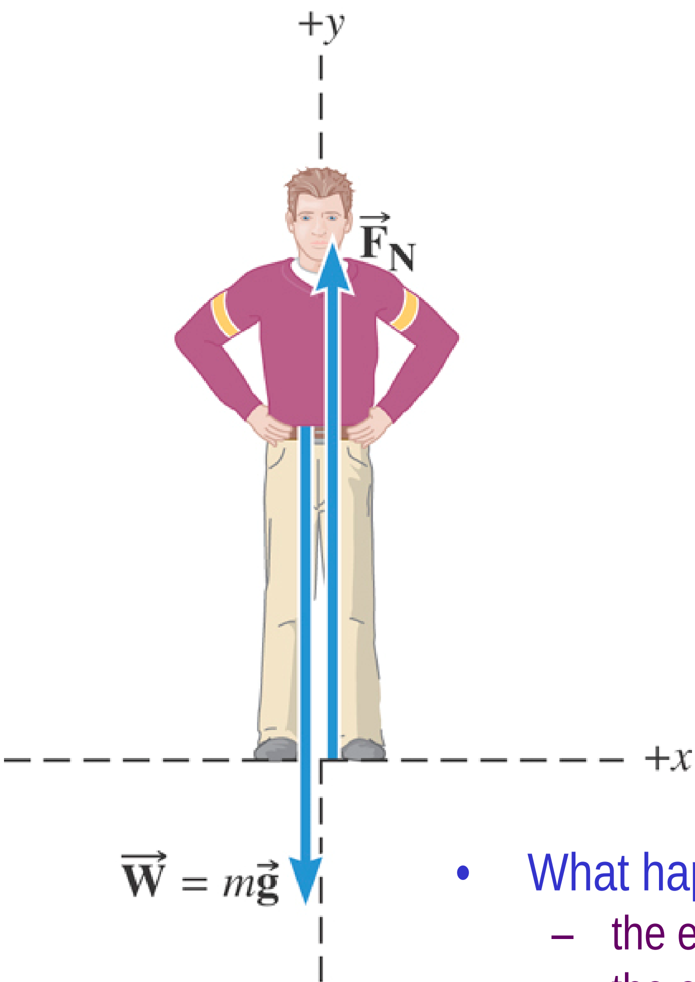
The apparent weight of an object is the reading on the scale.

It is equal to the normal force the man exerts on the scale.



(*a*) No acceleration ($\vec{v}$ = constant) (*b*) Upward acceleration (*c*) Downward acceleration (*d*) Free-fall

Apparent Weight



$$\sum F_y = +F_N - mg = ma$$

$$F_N = mg + ma$$

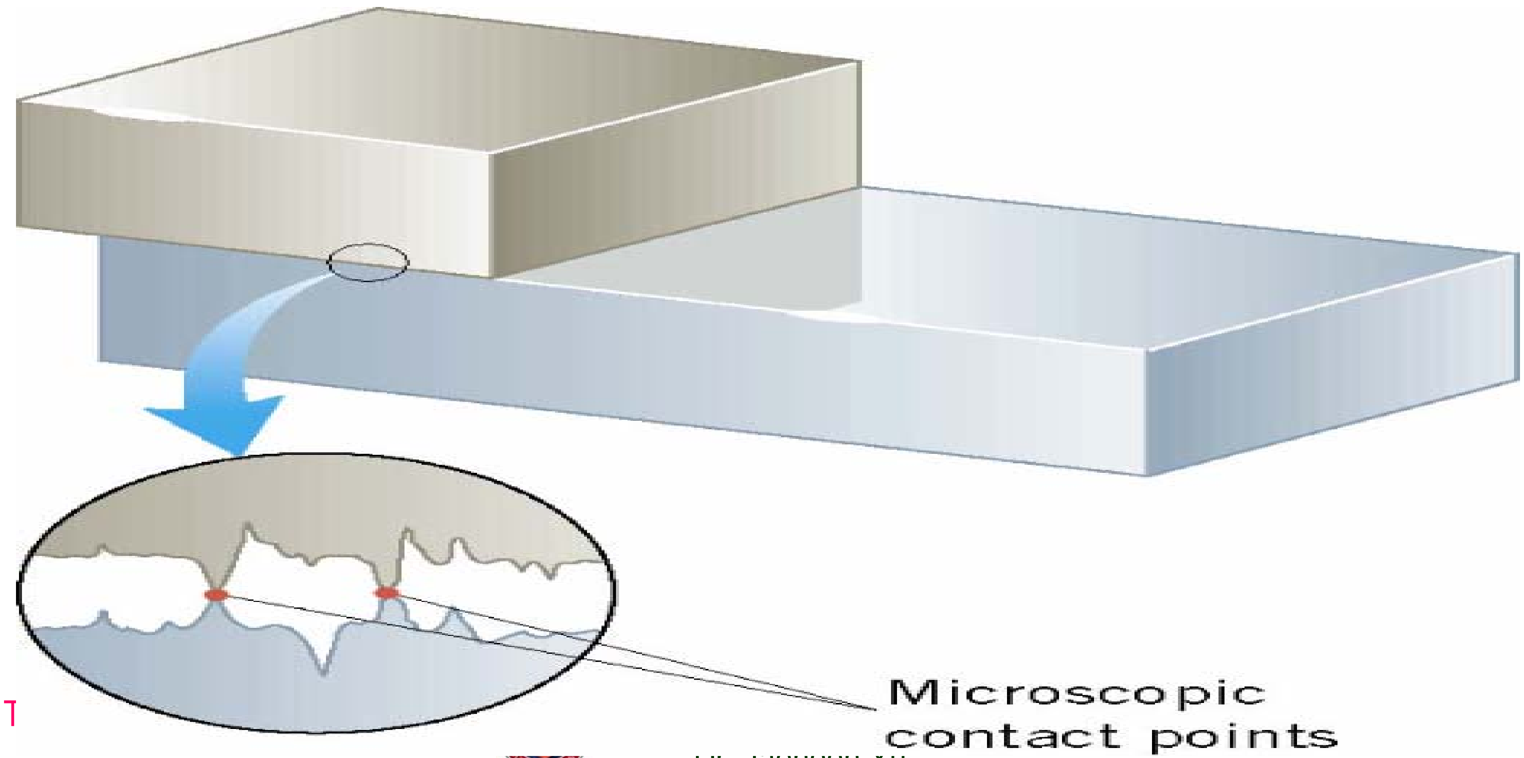
apparent weight

True weight

- What happens to the apparent weight when
  - the elevator is not moving — The same as true weight
  - the elevator is moving at a constant velocity — The same as true weight
  - the elevator is falling since its cables broke — 0

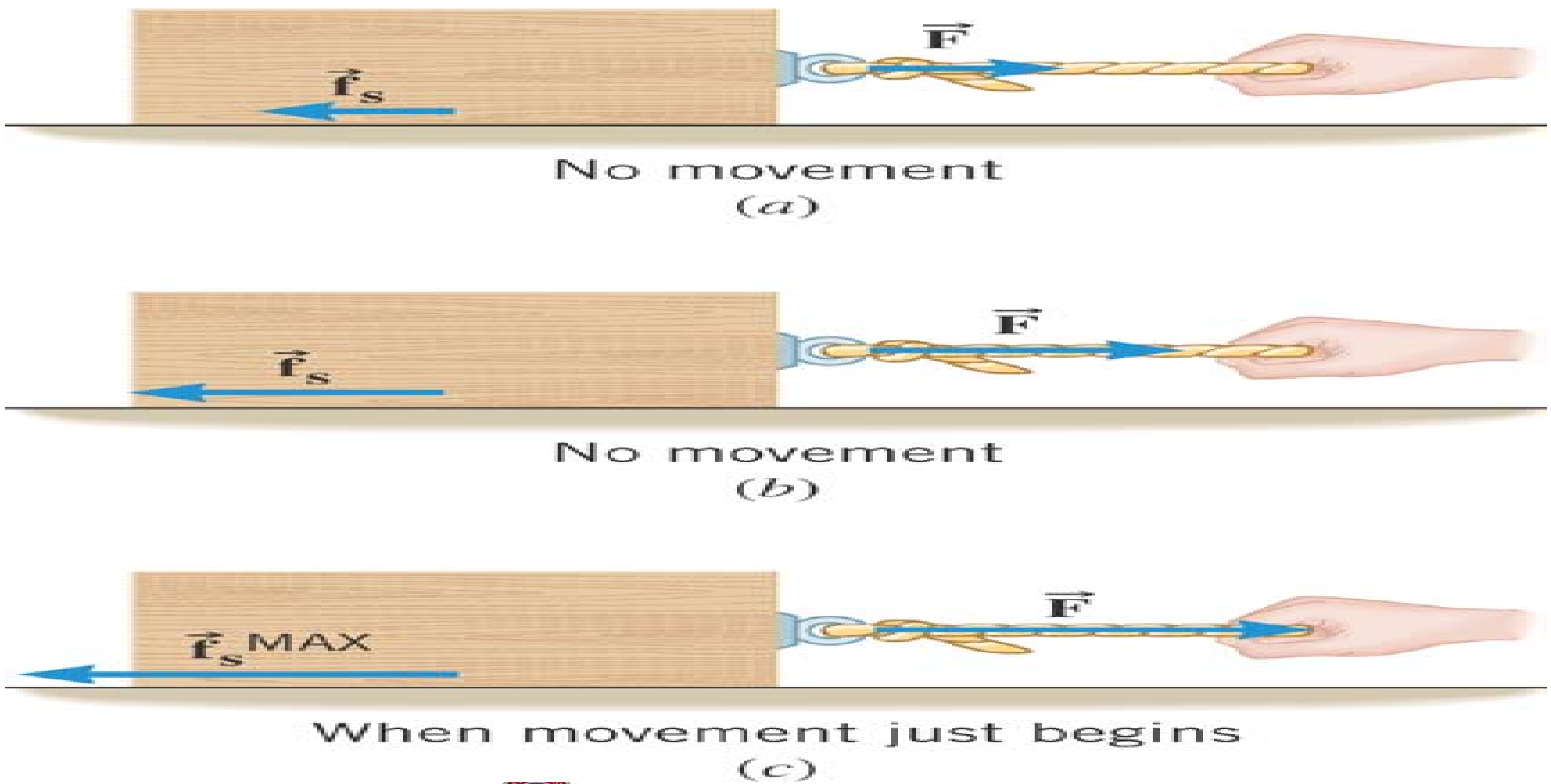
Friction Forces

When an object is in contact with a surface there is a force acting on that object. The component of this force that is parallel to the surface is called the ***frictional force***. *Resistive force exerted on a moving object due to viscosity or other types frictional property of the medium in or surface on which the object moves. Always opposite to the movement!!*



Static Friction

When the two surfaces are not sliding across one another the friction is called *static friction*. ***The resistive force exerted on the object up to the time just before the object starts moving.***



Magnitude of Static Friction

The magnitude of the static friction force can have any value from zero up to the maximum value.

$$f_s \le f_s^{MAX}$$

$$f_s^{MAX} = \mu_s F_N$$

$0 < \mu_s < 1$ is called the <u>coefficient of static friction</u>.

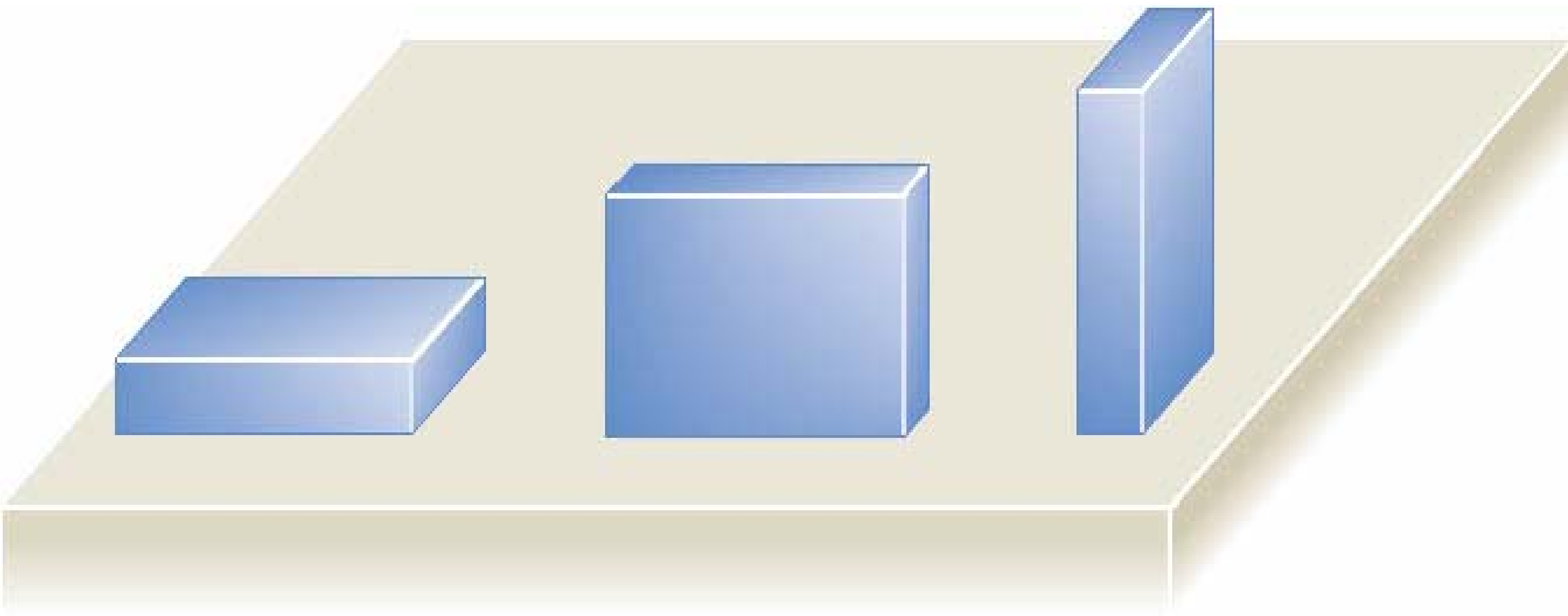
What is the unit? None

Once the object starts moving, there is <u>NO MORE</u> static friction!!

Kinetic friction applies during the move!!

Note that the magnitude of the frictional force <u>does not depend on the contact area of the surfaces</u>.

$$f_s^{MAX} = \mu_s F_N$$



Kinetic Friction

Static friction opposes the *impending* relative motion between two objects.

Kinetic friction opposes the relative sliding motion motions that actually does occur. ***The resistive force exerted on the object during its movement.***

$$f_k = \mu_k F_N$$

$$0 < \mu_k < 1$$ is called the coefficient of kinetic friction.

What is the direction of frictional forces? opposite to the movement

Coefficient of Friction

Table 4.2 **Approximate Values of the Coefficients of Friction for Various Surfaces***

Materials	Coefficient of Static Friction, μ_s	Coefficient of Kinetic Friction, μ_k
Glass on glass (dry)	0.94	0.4
Ice on ice (clean, 0 °C)	0.1	0.02
Rubber on dry concrete	1.0	0.8
Rubber on wet concrete	0.7	0.5
Steel on ice	0.1	0.05
Steel on steel (dry hard steel)	0.78	0.42
Teflon on Teflon	0.04	0.04
Wood on wood	0.35	0.3

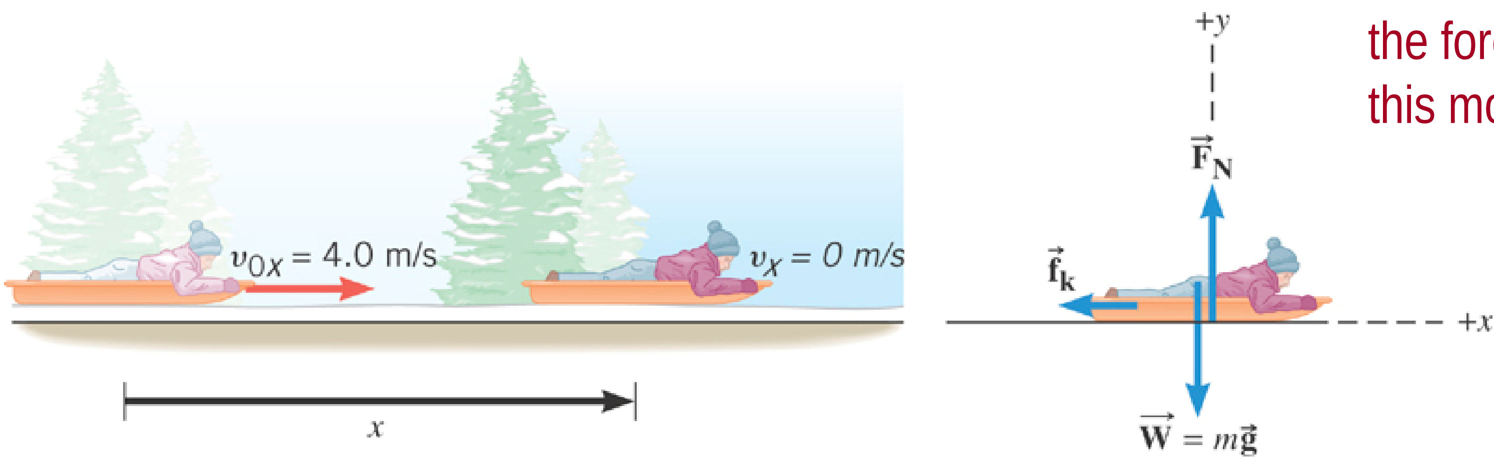
*The last column gives the coefficients of kinetic friction, a concept that will be discussed shortly.

What are these?

Ex. 10. Sled Riding

A sled is traveling at 4.00m/s along a horizontal stretch of snow. The coefficient of kinetic friction μ_k=0.0500. How far does the sled go before stopping?

What are the forces in this motion?



(a)

(b) Free-body diagram for the sled and rider

The sled comes to a halt because the kinetic frictional force opposes its motion and causes the sled to slow down.

Ex. 10 continued

What is the net force in y direction? 0 N

What is the net force in x direction? $F_x = -f_k = ma$

So the force equation becomes $f_k = \mu_k F_N = \mu_k mg$

Solve this for a $a = -\frac{f_k}{m} = -\frac{\mu_k \cancel{m} g}{\cancel{m}} = -\mu_k g =$

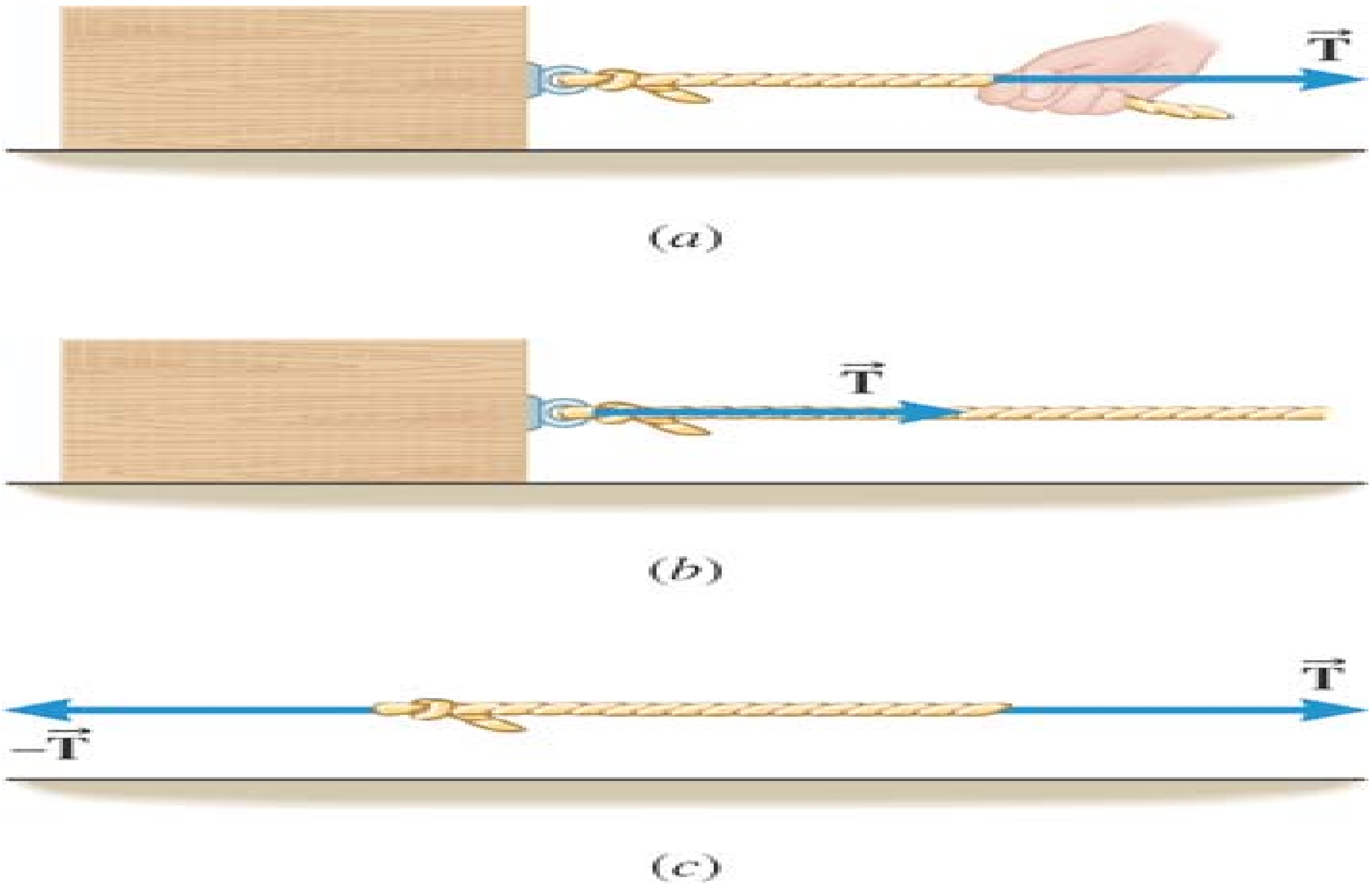
$$-0.05\left(9.80\,\mathrm{m/s^2}\right) = -0.49\,\mathrm{m/s^2}$$

Now that we know a and vi, pick the a kinematic equation to solve for distance $2ax = \left(v_f^2 - v_i^2\right)$

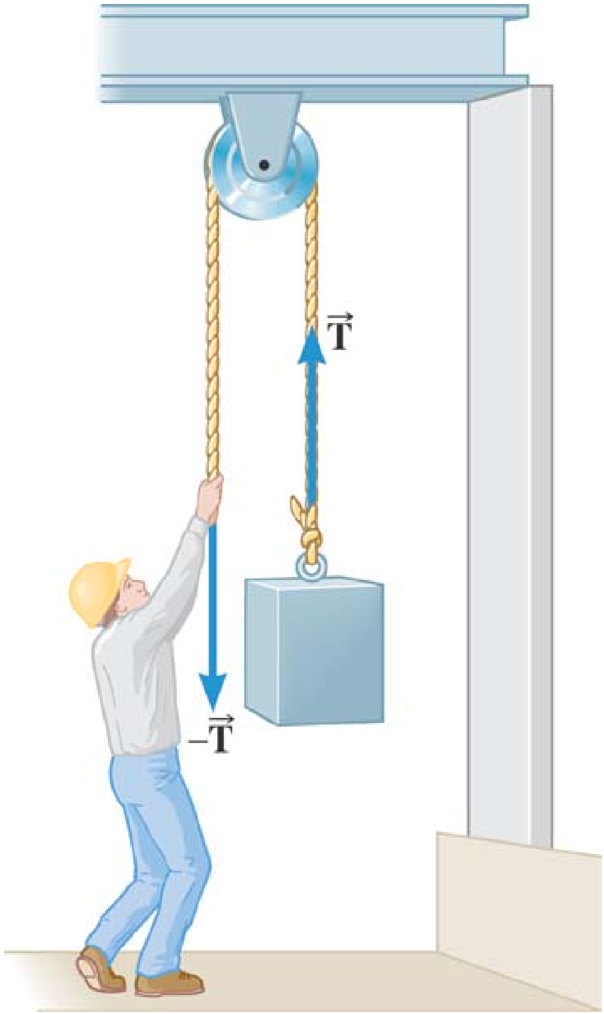
Solve this for x $x = \frac{\left(v_f^2 - v_i^2\right)}{2a} = \frac{\left(0 - 4.00^2\right)}{2 \cdot (-0.49)} = 16.3m$

The Tension Force

Cables and ropes transmit forces through *tension*.



Tension Force continued



A massless rope will transmit tension undiminished from one end to the other.

If the rope passes around a massless, frictionless pulley, the tension will be transmitted to the other end of the rope undiminished.

Some Basic Information

When Newton's laws are applied, *external forces* are only of interest!!

Why?

Because, as described in Newton's first law, an object will keep its current motion unless non-zero net external force is applied.

Normal Force, ***n*:**

Reaction force to the net force on a surface due to the surface structure of an object. Its direction is always perpendicular to the surface.

Tension, ***T*:**

The reactionary force by a stringy object against an external force exerted on it.

Free-body diagram

*A graphical tool which is a **diagram of external forces on an object** and is extremely useful analyzing forces and motion!! Drawn only on an object.*