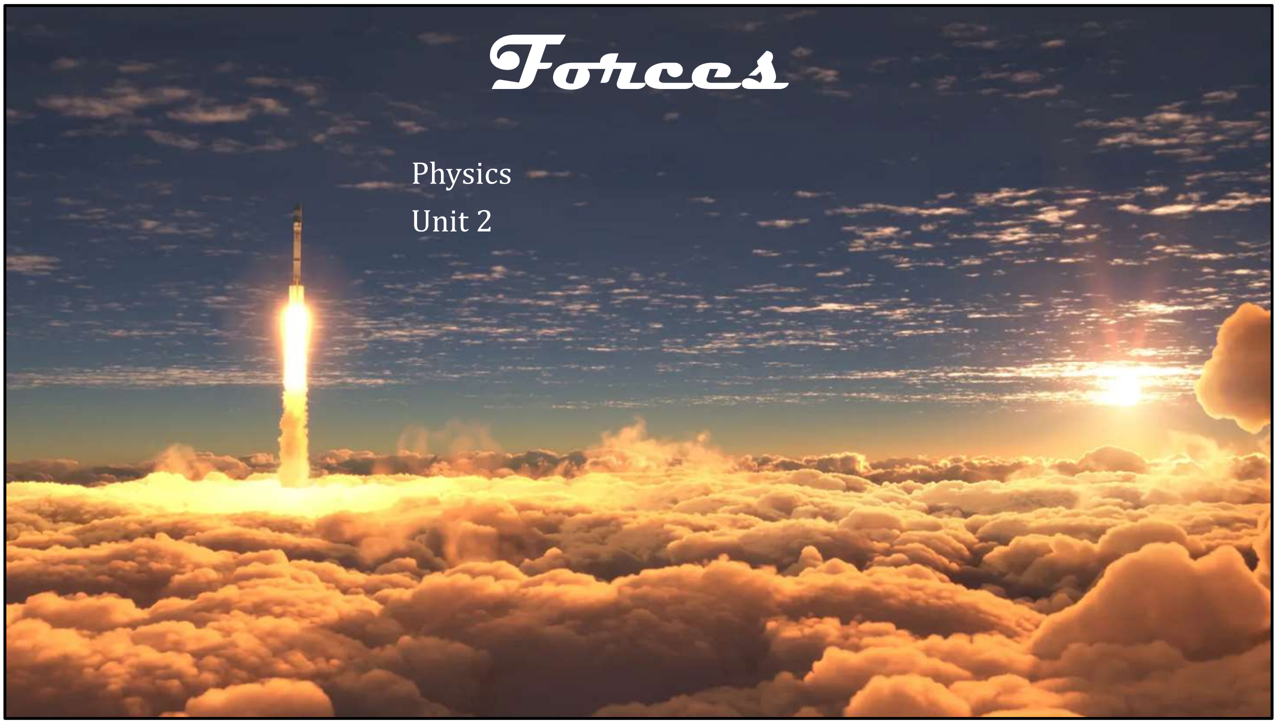

NAD 2023 Standards – Physical Science Force F1 (Newton's Laws)

Credits

- This Slideshow was developed to accompany the textbook
  - *OpenStax High School Physics*
    - *Available for free at https://openstax.org/details/books/physics*
    - *By Paul Peter Urone and Roger Hinrichs*
    - *2020 edition*
- Some examples and diagrams are taken from the *OpenStax College Physics, Physics,* and *Cutnell & Johnson Physics* 6th ed.

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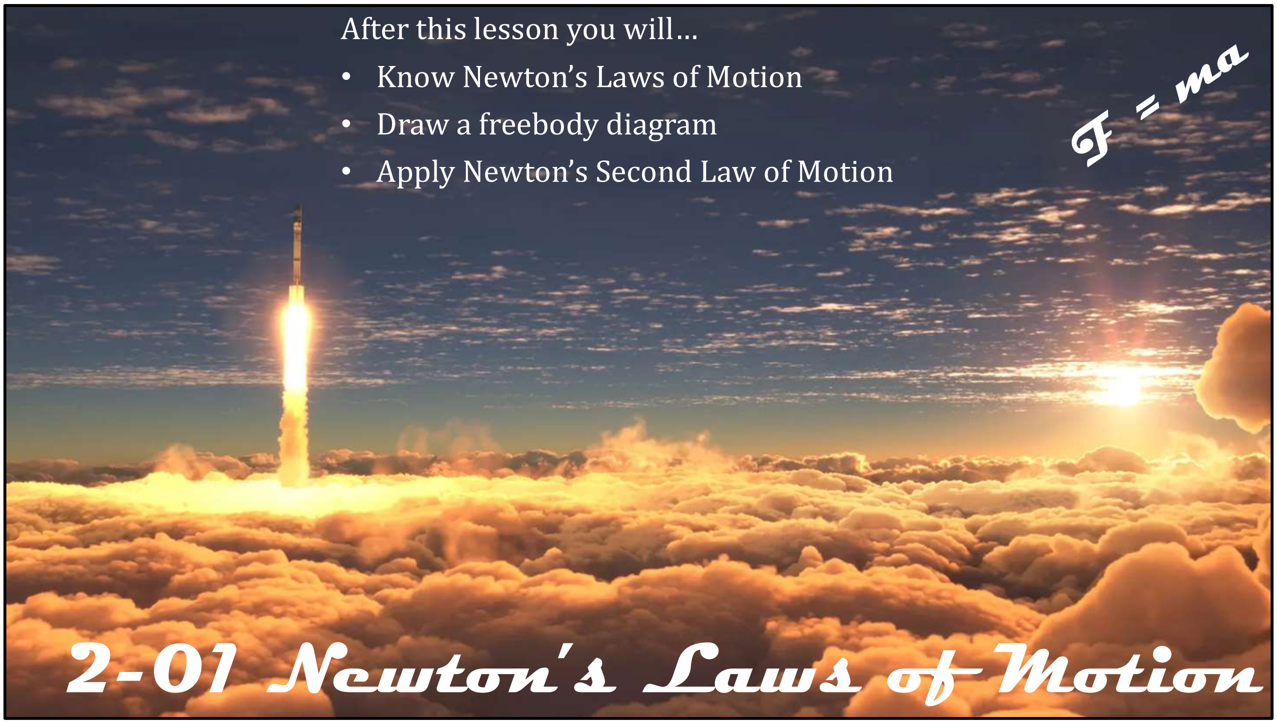


OpenStax High School Physics 4.1-4.4
OpenStax College Physics 2e 4.1-4.4

2-01 Newton's Laws of Motion

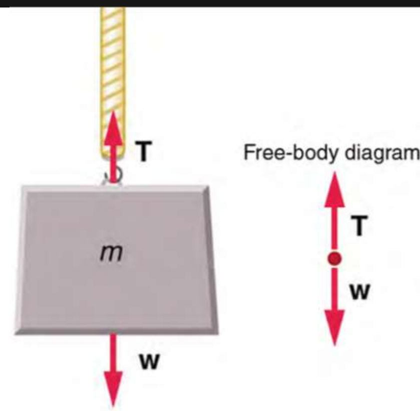
- Kinematics
  - How things move

- Dynamics
  - Why things move

- Force
  - A push or a pull
  - Is a vector
  - Unit: Newton (N)
  - Measured by a spring scale

2-01 Newton's Laws of Motion

- Free-body diagram
  - Picture of object with all the forces acting **on** the object



2-01 Newton's Laws of Motion

1. Place a marble on your desk so that it is at rest (not moving).
2. Observe the marble for a minute. What happens to it?
3. Without applying a force to the marble, make it move. Remember gravity is a force, so tipping the desk is the same as applying a force. Were you able to move the marble?
4. Roll the marble across your desk at a moderate speed so that it has no sidewise spin. Describe the path the marble took.
5. Without a sidewise spin, tipping the desk, or applying a force, can you make the marble take a curved path?

2. Nothing
3. No
4. Straight
5. No

2-01 Newton's Laws of Motion

Newton's First Law of Motion

- A body at rest remains at rest, or, if in motion, remains in motion at a constant velocity unless acted on by a net external force.

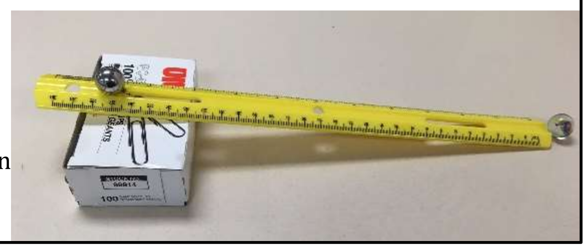
- Inertia
  - Property of objects to remain in constant motion or rest.
  - Mass is a measure of inertia

- Watch Eureka! 01
- Watch Eureka! 02

Example: Ice hockey, puck sits until someone hits it. Then it goes straight.

2-01 Newton's Laws of Motion

1. Make a ramp using the grooved ruler and a book.
2. Place a glass marble on your desk at the end of the ramp.
3. Release the other glass marble from the top of the ramp so that it rolls and hits the marble on the desk. Observe the velocity of the marble that was on the desk.
4. Place a glass marble on the desk at the end of the ramp.
5. Release the metal marble from the top of the ramp so that it rolls and hits the metal marble on the desk. Observe the velocity of the metal marble.
6. Which marble on the desk (1st or 2nd) had a larger force applied to it?
7. Which marble had the larger final velocity?
8. What was the marble's initial velocity in both cases?
9. Define acceleration.
10. Which marble had the larger acceleration?
11. What is the relationship between force and acceleration



6. 2^{nd}
7. 2^{nd}
8. 0
9. $a = \frac{\Delta v}{\Delta t}$
10. 2^{nd}
11. Bigger force = bigger acceleration

2-01 Newton's Laws of Motion

1. Place a glass marble on your desk at the end of the ramp.
2. Release the other glass marble from the top of the ramp so that it rolls and hits the marble on the desk. Observe the velocity of the marble that was on the desk.
3. Place a metal marble on the desk at the end of the ramp.
4. Release the glass marble from the top of the ramp so that it rolls and hits the metal marble on the desk. Observe the velocity of the metal marble.
5. Which marble on the desk (glass or metal) had a larger force applied to it?
6. Which marble had the larger final velocity?
7. Which marble had the larger acceleration?
8. Which marble had more mass?
9. What is the relationship between mass and acceleration?

5. Same
6. Glass
7. Glass
8. Metal
9. Bigger mass = smaller acceleration

2-01 Newton's Laws of Motion

Newton's Second Law of Motion

- Acceleration of a system is directly proportional to and in the same direction as the net force acting on the system, and inversely proportional to its mass.

$$\boldsymbol{F}_{net} = m\boldsymbol{a}$$

- Net force is the vector sum of all the forces.

- Watch Eureka! 03
- Watch Eureka! 04
- Watch Eureka! 05

2-01 Newton's Laws of Motion

1. Take two spring scales and hook their ends together. Lay them horizontally on the desk.
2. Gently pull on one spring scale so it reads 4 N.
3. What do the scales read for the force?
4. Apply 3-N force. What do the scales read?
5. With the scales hooked together, try to pull only one scale so that the other one does not experience a force. Were you successful, explain.

3. 4 N, 4 N
4. 3 N, 3 N
5. No (there is some friction involved in the spring scales and that can cause unequal force readings)

2-01 Newton's Laws of Motion

Newton's Third Law of Motion

- Whenever one body exerts a force on a second body, the first body experiences a force that is equal in magnitude and opposite in direction to the force that it exerts.

- Every force has an equal and opposite reaction force.

- You push down on your chair, so the chair pushed back up on you.

2-01 Newton's Laws of Motion

- A football player named Al is blocking a player on the other team named Bob. Al applies a 1500 N force on Bob. If Bob's mass is 100 kg, what is his acceleration?
- What is the size of the force on Al?
- If Al's mass is 75 kg, what is his acceleration?

$$F = ma$$
$$1500\ N = (100\ kg)a \rightarrow a = 15\ m/s^2$$

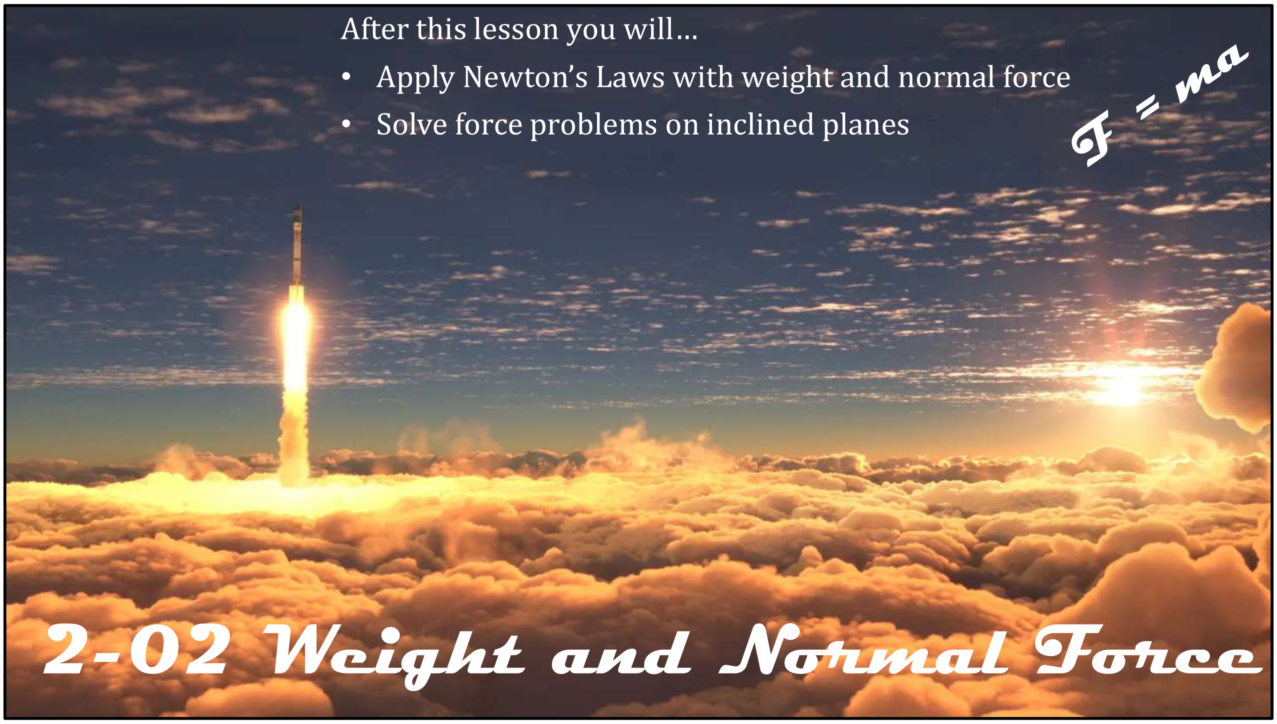
1500 N (Newton's 3rd Law)

$$F = ma$$
$$1500\ N = (75\ kg)a \rightarrow a = 20\ m/s^2$$

2-01 Newton's Laws of Motion

- A 0.046 kg golf ball hit by a driver can accelerate from rest to 67 m/s in 1 ms while the driver is in contact with the ball. How much average force does the golf ball experience?

$$v = at + v_0$$
$$67\frac{m}{s} = a(1 \times 10^{-3}\ s) + 0$$
$$67000\frac{m}{s^2} = a$$
$$F = ma$$
$$F = (0.046\ kg)\left(67000\frac{m}{s^2}\right)$$
$$F = 3082\ N$$



OpenStax High School Physics 4.1-4.2
OpenStax College Physics 2e 4.3-4.5

2-02 Weight and Normal Force

- **Weight**
  - Measure of force of gravity
  - $F = ma$
  - Objects near earth accelerate downward at 9.80 m/s^2
  - $W = mg$
  - Unit: N
  - Depends on local gravity

- **Mass**
  - Not a force
  - Measure of inertia or amount of matter
  - Unit: kg
  - Constant

- Watch Eureka! 6
- Remember!!!
  - Weight is a Force
- Watch Eureka 7

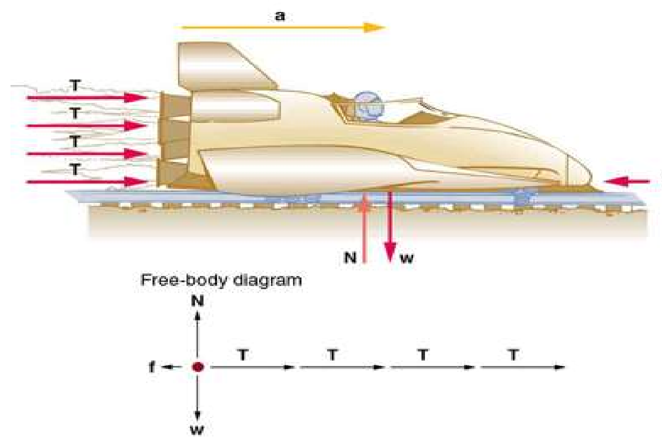
2-02 Weight and Normal Force

- **Problems-Solving Strategy**

1. Identify the principles involved and draw a picture
2. List your knowns and Draw a free-body diagram
3. Apply $F_{net} = ma$
4. Check your answer for reasonableness

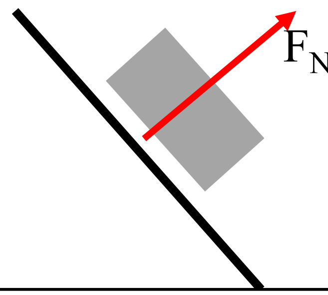
2-02 Weight and Normal Force

- Free-body diagram
  - Draw only forces acting on the object
  - Represent the forces with vector arrows



2-02 Weight and Normal Force

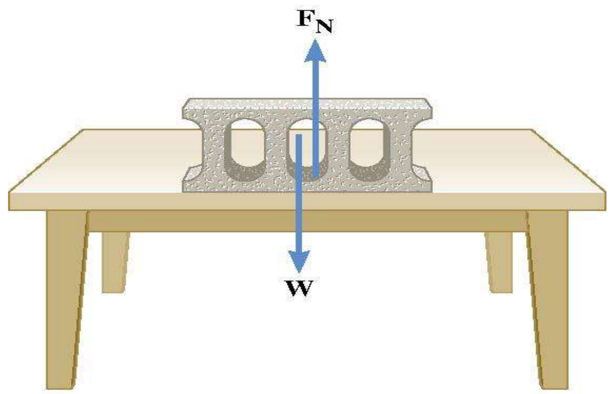
- When two objects touch there is often a force
- Normal Force
  - Perpendicular component of the contact force between two objects



2-02 Weight and Normal Force

- Weight pushes down
- So the table pushes up
  - Called Normal force
  - Newton's 3rd Law

- Normal force doesn't always = weight
- Draw a freebody diagram to find equation



2-02 Weight and Normal Force

- A 30-kg box of books is sitting on the floor. A 20-kg child is sitting on the box. What is the normal force between the child and the box?

- What is the normal force between the box and the floor?

$$F = ma$$
$$F_N - mg = 0$$
$$F_N - (20\ kg)\left(9.8\frac{m}{s^2}\right) = 0$$
$$F_N = 196\ N$$

$$F = ma$$
$$F_N - mg = 0$$
$$F_N - (50\ kg)\left(9.8\frac{m}{s^2}\right) = 0$$
$$F_N = 490\ N$$

2-02 Weight and Normal Force

1. Hang the mass from the spring scale. The scale will measure the force applied to hold the mass in place. This is the weight.
2. What is the weight of your mass?
3. Carefully watch the spring scale as you quickly move the scale upwards. What happens to the weight?
4. Carefully watch the spring scale as you quickly move the scale downwards. What happens to the weight?
5. The other weights are called apparent weight and is what you feel as the net force pulling you down. An upward acceleration produces a ____________________ apparent weight. A downward acceleration produces a ___________________ apparent weight.

- When a problem asks for apparent weight, find the normal force

3. More
4. Less
5. larger; smaller

2-02 Weight and Normal Force

- A lady is weighing some bananas in a grocery store when the floor collapses. If the bananas mass is 2 kg and the floor is accelerating at −2.25 m/s^2, what is the apparent weight (normal force) of the bananas?

- F_N = 15.1 N

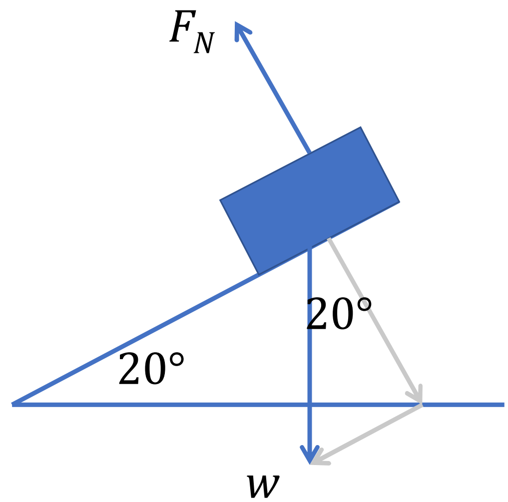
Draw freebody diagram and solve

$$F_{net} = F_N - w = ma$$
$$F_N - (2\ kg)\left(9.8\frac{m}{s^2}\right) = (2\ kg)\left(-2.25\frac{m}{s^2}\right)$$
$$F_N = 15.1\ N$$

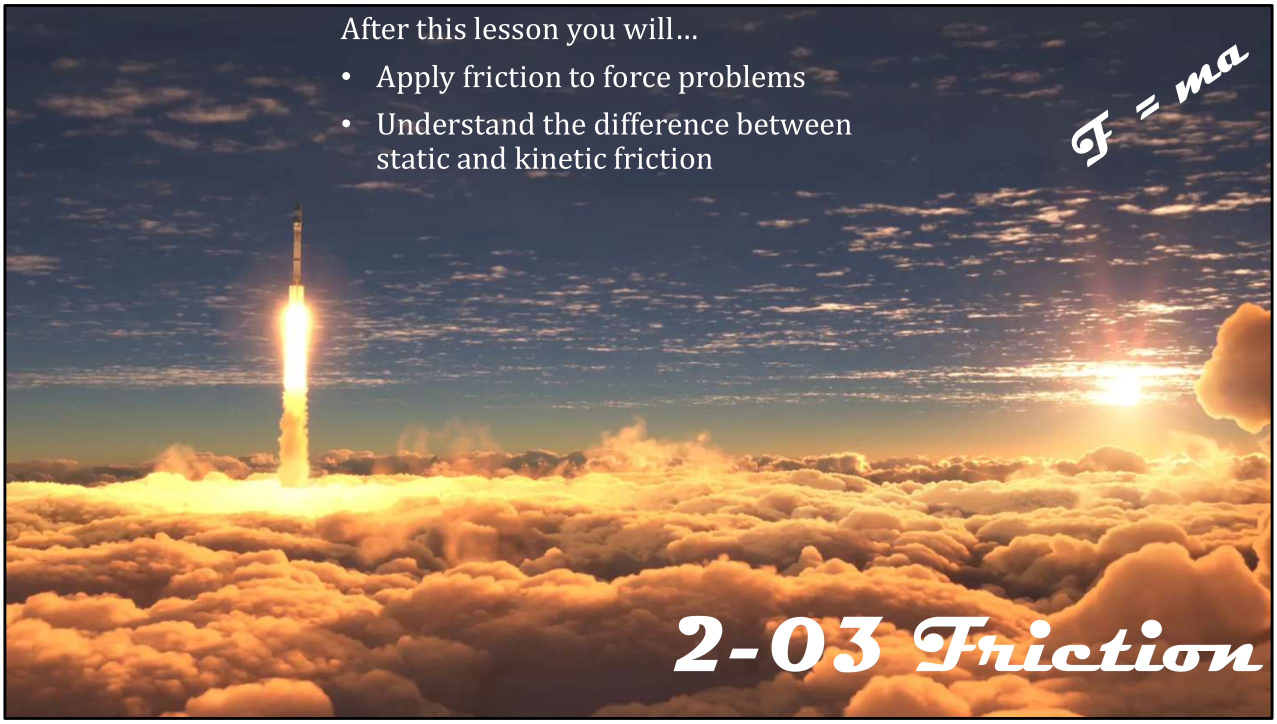
2-02 Weight and Normal Force

- A box is sitting on a ramp angled at 20°. If the box weighs 50 N, what is the normal force on the box?

- 47 N



$$w_\perp = w \cdot \cos 20° = 47\ N$$
$$F_N - w_\perp = ma = 0$$
$$F_N = w_\perp = 47\ \text{N}$$

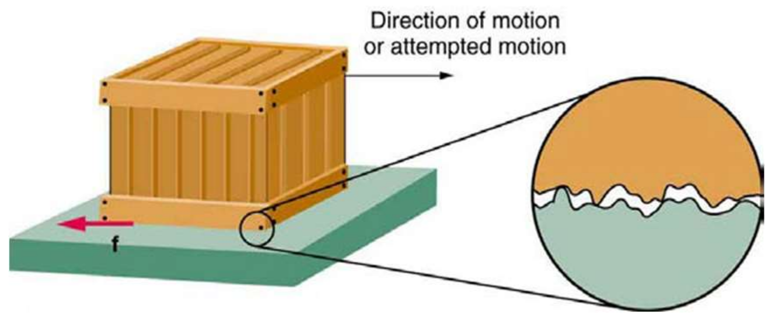


OpenStax High School Physics 4.2
OpenStax College Physics 2e 5.1

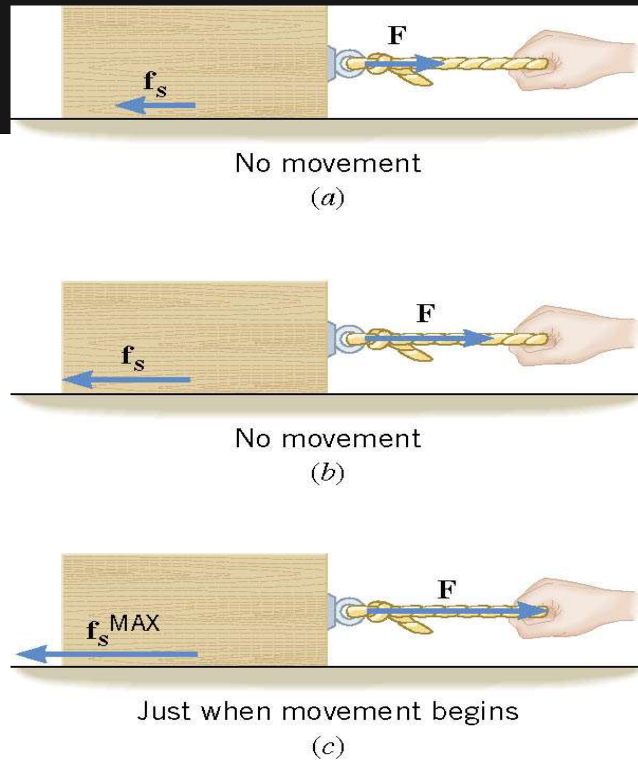
2-03 Friction

- Normal force – perpendicular to surface
- Friction force – parallel to surface, and opposes motion

- Comes from rough surface



- Static Friction
  - Keeps things from moving.
  - Cancels out applied force until the applied force gets too big.
  - Depends on force pushing down and roughness of surface



2-03 Friction

- Static Friction
  - Depends on force pushing down and roughness of surface
- $f_S \leq \mu_S F_N$
  - More pushing down (F_N), more friction
  - μ_S is coefficient of static friction (0.01 to 1.5)

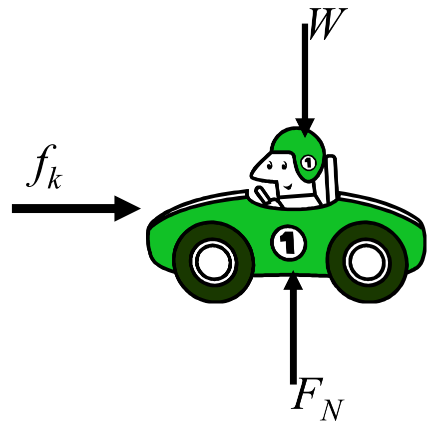
2-03 Friction

- Kinetic Friction
  - Once motion happens
  - $f_k = \mu_k F_N$
  - f_k is usually less than f_s

2-03 Friction

- A car skids to a stop after initially going 30.0 m/s. μ_k = 0.800. How far does the car go before stopping?

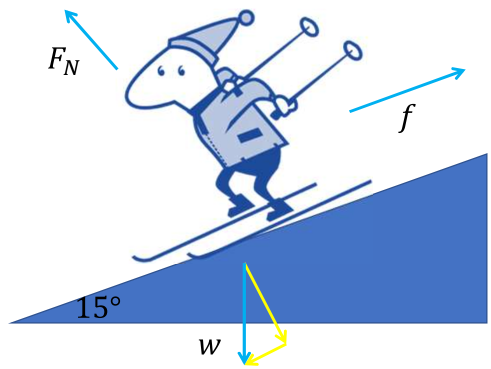
- 57.3 m



$$y\colon\ F_N = W = mg$$
$$x\colon\ f_k = \mu_k F_N = \mu_k mg$$
$$F = ma$$
$$\mu_k mg = ma \rightarrow\ \mu_k g = a$$
$$v^2 = v_0^2 + 2ax \rightarrow\ v^2 = v_0^2 + 2\mu_k g x$$
$$0 = \left(30.0\frac{m}{s}\right)^2 + 2(0.800)\left(-9.80\frac{m}{s^2}\right)x$$
$$-900\left(\frac{m}{s}\right)^2 = \left(15.7\frac{m}{s^2}\right)x \rightarrow x = 57.3\ m$$

2-03 Friction

- A 65-kg skier is coasting downhill on a 15° slope. Assuming the coefficient of friction is that of waxed wood on snow, what is the skier's acceleration?
- 1.59 m/s^2 downhill



Perpendicular direction:

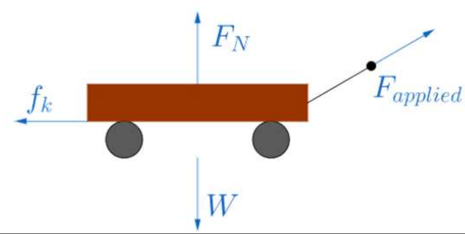
$$F_N - w\cos 15° = ma$$
$$F_N - mg\cos 15° = m(0)$$
$$F_N - (65\ kg)\left(9.8\frac{m}{s^2}\right)\cos 15° = 0$$
$$F_N = 615.2948\ N$$

parallel direction:

$$f - w\sin 15° = ma$$
$$\mu_k F_N - mg\sin 15° = ma$$
$$(0.1)(615.2948\ N) - (65\ kg)\left(9.8\frac{m}{s^2}\right)\sin 15° = (65\ kg)a$$
$$-103.338\ N = (65\ kg)a$$
$$-1.59\frac{m}{s^2} = a$$

2-03 Friction

- While hauling firewood to the house, you pull a 100-kg wood-filled wagon across level ground at a constant velocity. You pull the handle with a force of 230 N at 30° above the horizontal. What is the coefficient of friction between the wagon and the ground?



$$y: F_N - W + 230\ N\ sin\ 30° = ma$$
$$F_N - (100\ kg)\left(9.8\frac{m}{s^2}\right) + 115\ N = (100\ kg)(0)$$
$$F_N = 865\ N$$

$$x: 230\ N\ cos\ 30° - f_k = ma$$
$$199.1858\ N - \mu_k F_N = ma$$
$$199.1858\ N - \mu_k(865\ N) = (100\ kg)(0)$$
$$199.1858\ N = (865\ N)\mu_k$$
$$\mu_k = 0.230$$

OpenStax High School Physics 5.5, 4.3, 4.4
OpenStax College Physics 2e 4.5

2-04 Tension, Hooke's Law, and Equilibrium

- Do the lab on your worksheet

2-04 Tension, Hooke's Law, and Equilibrium

- Hooke's Law
  - For springs or forces that deform (change shape)
  - For small deformations (no permanent change)
  - $F_S = k\Delta x$
    - k = spring constant and is unique to each spring
    - Δx = the distance the spring is stretched/compressed
  - Hooke's Law is the reason we can use a spring scale to measure force

2-04 Tension, Hooke's Law, and Equilibrium

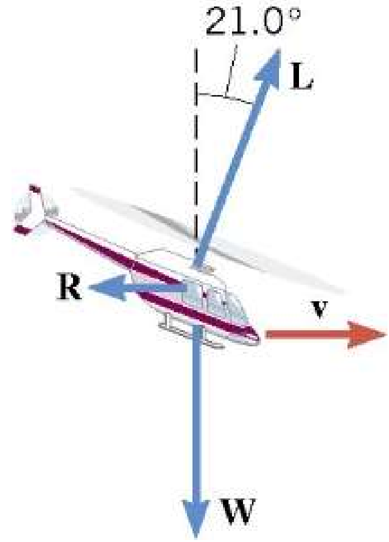
- Tension
  - Pulling force from rope, chain, etc.
  - Everywhere the rope connects to something, there is an identical tension

2-04 Tension, Hooke's Law, and Equilibrium

- Equilibrium
  - No acceleration
  - $F_{net} = ma$
  - $F_{net} = 0$

2-04 Tension, Hooke's Law, and Equilibrium

- The helicopter in the drawing is moving horizontally to the right at a constant velocity. The weight of the helicopter is 53,800 N. The lift force **L** generated by the rotating blade makes an angle of 21.0° with respect to the vertical. What is the magnitude of the lift force?
- 57600 N

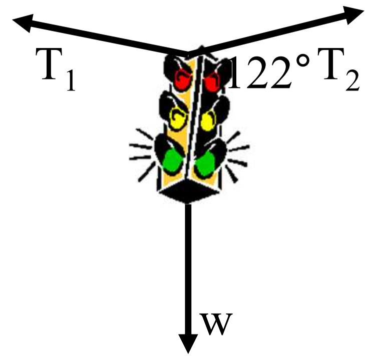


<u>y-components</u>

$$L\cos 21.0° - W = ma$$
$$L\cos 21.0° - 53800\ N = 0$$
$$L\cos 21.0° = 53800\ N$$
$$L = 57600\ N$$

2-04 Tension, Hooke's Law, and Equilibrium

- A stoplight is suspended by two cables over a street. Weight of the light is 110 N and the cables make a 122° angle with each side of the light. Find the tension in each cable.



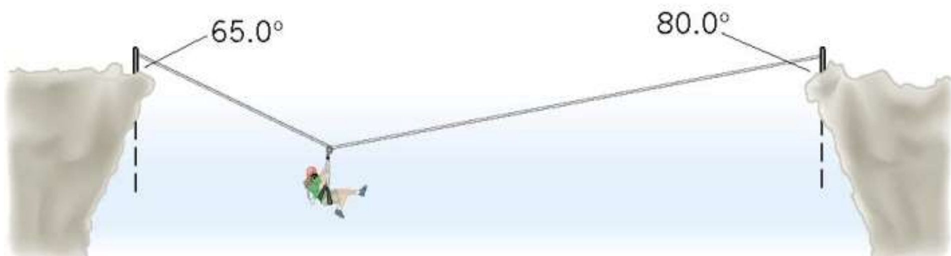
- 104 N

Solve on board by making a table

$$F_x:\ T_2 \cos 32° - T_1 \cos 32° = 0$$
$$T_2(.8480) - T_1(.8480) = 0$$
$$T_1 = T_2$$
$$F_y: -w + T_1 \sin 32° + T_2 \sin 32° = 0$$
$$-110\ N + T_1(.5299) + T_2(.5299) = 0$$
$$-110\ N + 1.0598 T_1 = 0$$
$$1.0598\ T_1 = 110\ N$$
$$T_1 = T_2 = 103.8\ N$$

2-04 Tension, Hooke's Law, and Equilibrium

- A mountain climber, in the process of crossing between two cliffs by a rope, pauses to rest. She weighs 535 N. Find the tensions in the rope to the left and to the right of the mountain climber.



x-direction

$$-T_1 \sin 65° + T_2 \sin 80° = ma = 0$$
$$T_2 = 0.920289 T_1$$

y-direction

$$T_1 \cos 65° + T_2 \cos 80° - w = ma = 0$$
$$T_1 \cos 65° + (0.9202889 T_1) \cos 80° - 535\ N = 0$$
$$0.582424777 T_1 = 535\ N$$
$$T_1 = 919\ N$$
$$T_2 = 845\ N$$

2-04 Tension, Hooke's Law, and Equilibrium

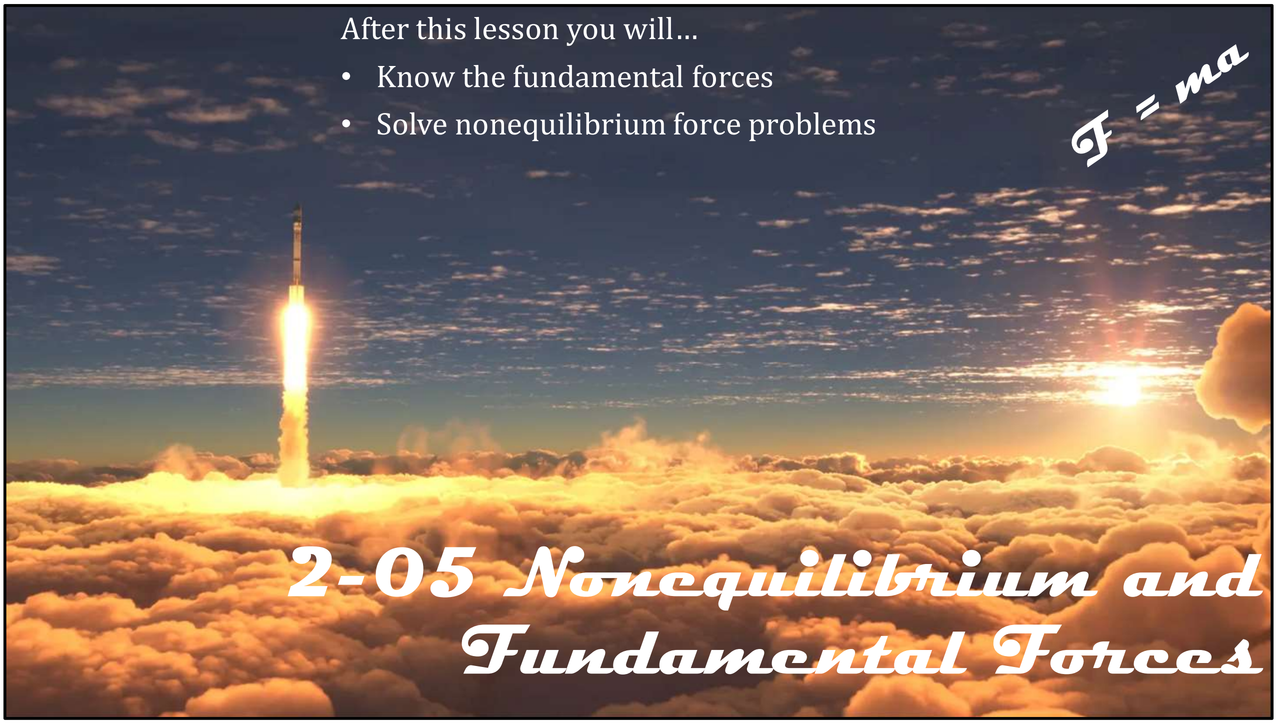
- A 10-g toy plastic bunny is connected to its base by a spring. The spring is compressed and a suction cup on the bunny holds it to the base so that the bunny doesn't move. If the spring is compressed 3 cm and has a constant of 330 N/m, how much force must the suction cup provide?

$$F_S - w - F_{cup} = ma = 0$$

$$kx - mg - F_{cup} = 0$$

$$\left(330\frac{N}{m}\right)(0.03\ m) - (0.010\ kg)\left(9.8\frac{m}{s^2}\right) - F_{cup} = 0$$

$$F_{cup} = 9.8\ N$$



OpenStax High School Physics 4.3
OpenStax College Physics 2e 4.6-4.8

2-05 Nonequilibrium and Fundamental Forces

- Four Basic Forces
  - All forces are made up of only 4 forces

  - Gravitational - gravity
  - Electromagnetic – static electricity, magnetism
  - Weak Nuclear - radioactivity
  - Strong Nuclear – keeps nucleus of atoms together

2-05 Nonequilibrium and Fundamental Forces

- All occur because particles with that force property play catch with a different particle
  - Electromagnetic uses photons
  - Scientists are trying to combine all forces together in Grand Unified Theory
  - Have combined electric, magnetic, weak nuclear
- Gravity is the weakest
  - We feel it because the electromagnetic cancels out over large areas
- Nuclear forces are strong but only over short distance

Close on combining gravitational too

2-05 Nonequilibrium and Fundamental Forces

- A 1380-kg car is moving due east with an initial speed of 27.0 m/s. After 8.00 s the car has slowed down to 17.0 m/s. Find the magnitude and direction of the net force that produces the deceleration.

Use kinematics to find *a*

$$v_0 = 27.0\frac{m}{s}, t = 8.00\ s, v = 17.0\frac{m}{s}, a = ?$$

$$v = at + v_0$$

$$17\frac{m}{s} = a(8\ s) + 27\frac{m}{s}$$

$$a = -1.25\frac{m}{s^2}$$

Use Newton's 2nd Law

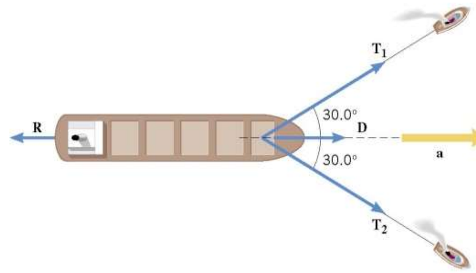
$$F = ma$$

$$F = (1380\ kg)\left(-1.25\frac{m}{s^2}\right) = -1725\ N$$

1725 N West

2-05 Nonequilibrium and Fundamental Forces

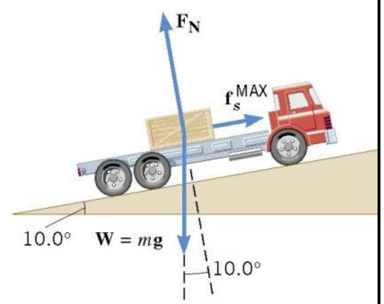
- A supertanker of mass $m = 1.50 \times 10^8$ kg is being towed by two tugboats, as in the picture. The tensions in the towing cables apply the forces T_1 and T_2 at equal angles of 30.0° with respect to the tanker's axis. In addition the tanker's engines produce a forward drive force D, whose magnitude is $D = 75.0 \times 10^3$ N. Moreover, the water applies an opposing force R, whose magnitude is $R = 40.0 \times 10^3$ N. The tanker moves forward with an acceleration of 2.00×10^{-3} m/s². Find the magnitudes of the tensions T_1 and T_2.



$$F_{net} = ma$$
$$y: T_1 \sin 30° - T_2 \sin 30° = ma = 0$$
$$T_1 = T_2$$
$$x: T_1 \cos 30° + T_2 \cos 30° + D - R = ma$$
$$T_1\left(\frac{\sqrt{3}}{2}\right) + T_1\left(\frac{\sqrt{3}}{2}\right) + 75 \times 10^3\ N - 40.0 \times 10^3\ N$$
$$= (1.50 \times 10^8\ kg)\left(2.00 \times 10^{-3}\ \frac{m}{s^2}\right)$$
$$\sqrt{3}T_1 = 2.65 \times 10^5\ N$$
$$T_1 = T_2 = 1.53 \times 10^5\ N$$

2-05 Nonequilibrium and Fundamental Forces

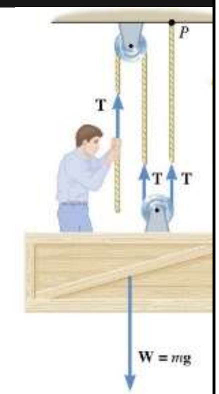
- A flatbed truck is carrying a crate up a 10.0° hill as in the picture. The coefficient of the static friction between the truck bed and the crate is $\mu_s = 0.350$. Find the maximum acceleration that the truck can attain before the crate begins to slip backward relative to the truck.



$$F_{net} = ma$$
$$y: F_N - w\cos 10° = ma = 0$$
$$F_N = mg\cos 10°$$
$$x: f_s - w\sin 10° = ma$$
$$\mu_s F_N - mg\sin 10° = ma$$
$$0.350(\cancel{m}g\cos 10°) - \cancel{m}g\sin 10° = \cancel{m}a$$
$$1.68\frac{m}{s^2} = a$$

2-05 Nonequilibrium and Fundamental Forces

- A window washer on a scaffold is hoisting the scaffold up the side of a building by pulling downward on a rope, as in the picture. The magnitude of the pulling force is 540 N, and the combined mass of the worker and the scaffold is 155 kg. Find the upward acceleration of the unit.



$$3T - w = ma$$

$$3(540\ N) - (155\ kg)\left(9.8\frac{m}{s^2}\right) = (155\ kg)a$$

$$0.65\frac{m}{s^2} = a$$