

## PHYSICS 151 – Notes for Online Lecture #11

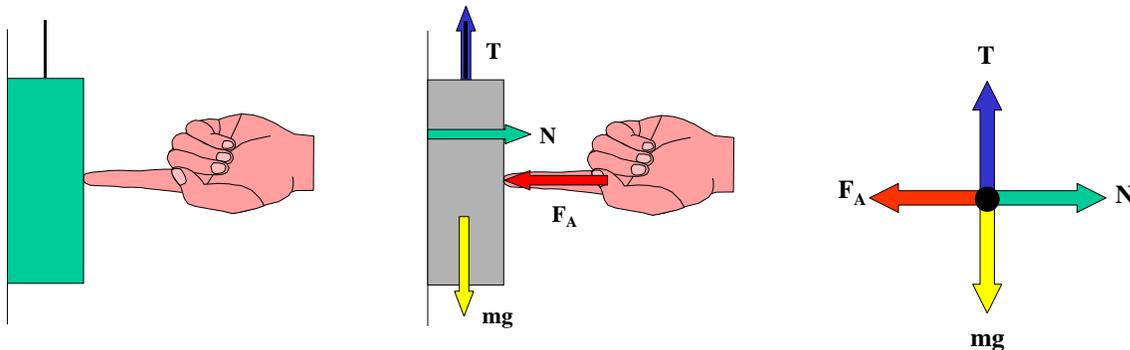
A free-body diagram is a way to represent all of the forces that act on a body. A free-body diagram makes solving Newton's second law for a given situation easier, because you're modeling the system as something simpler than it actually is.

To draw a free-body diagram:

1. Draw a separate diagram for each body in the problem. If you have to deal with two masses, for example, you need two diagrams.
2. Represent the body as a point. For now, we don't know how to deal with forces that cause rotations. We're only dealing with forces that cause linear motion. Regardless of what body we're dealing with, we're going to represent it as a point.
3. Draw each of the forces that acts directly on the body. There are two important ideas here: "acts directly" and "on". Recall that only forces that act directly on a body are counted when you sum up the net force. The second operative word is "on": make sure that you have included only those forces acting **on** the body. Don't include forces that the body exerts on other things, or forces that aren't exerted on the body that you're analyzing.
4. Draw all of the forces so that their tails are at the dot and their heads point in the direction of the force.
5. Label all of the forces

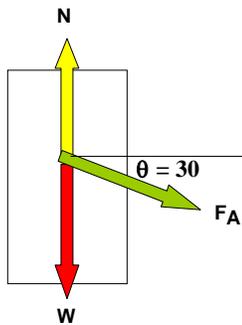
**Ex. 12-1:** Draw a free-body diagram for the example of a hand holding a block against the wall that is also suspended by a string.

Solution: The block is represented as a point. We have four forces: tension due to the string, the applied force from the hand, the weight of the block and the normal force of the wall on the block. The free-body diagram looks like:



**Ex. 12-3:** A person is moving a 35 kg file cabinet by pushing it downward at an angle of  $30^\circ$  below the horizontal with an applied force of 35 N. What is the acceleration of the file cabinet?

If you draw a free-body diagram for this situation, it will look like this:



Part of the applied force acts to the right and part acts downward. The cabinet is accelerating to the right – not up and down, so the net force on the cabinet must be zero.

That means that part of the applied force adds with the weight. The normal force has to support both the weight of the box and the force downward that the person is applying. Regardless of the exact amount the applied force contributes downward, the normal force will always be greater than the weight.

The equation for Newton's second law in the y-direction is  $\sum F_y = N - mg - F_A \sin 30^\circ = 0$  which allows one to solve for the normal force as  $N = mg + F_A \sin 30^\circ$ . The importance of the normal force will soon become apparent as we talk about friction. The equation for Newton's second law in the x-direction is  $\sum F_x = F_A \cos 30^\circ = ma_x$  for which one can solve for the acceleration  $a_x = \frac{F_A \cos 30^\circ}{m}$ .

$$\begin{aligned} \sum F_x &= F_A \cos \theta = ma_x \\ a_x &= \frac{F_A \cos \theta}{m} = \frac{(35 \text{ N}) \cos 30^\circ}{(35 \text{ kg})} = 0.87 \frac{\text{m}}{\text{s}^2} \end{aligned}$$

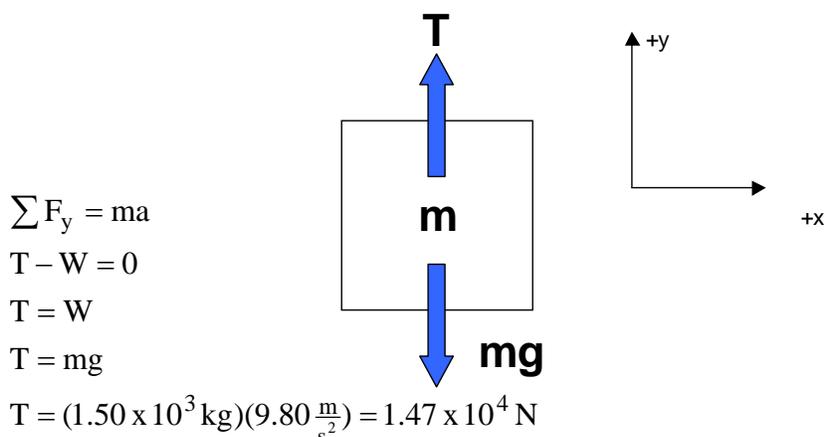


How would the problem change if the force were applied  $30^\circ$  above the horizontal.

(It wouldn't change our answer for acceleration at all in the present problem. It would change it quite a bit if we were considering friction because it would greatly affect the normal force.)

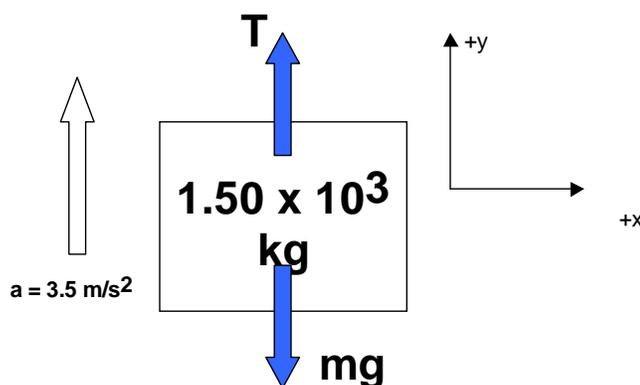
**Ex. 12-2:** An elevator is being planned for a building. If the elevator has a mass of  $1.50 \times 10^3$  kg, what tension must the supporting cable be able to withstand?

Draw the forces acting on the elevator.



The elevator designer forgot that the plans specified that the elevator would experience a maximum upward acceleration of  $3.50 \text{ m/s}^2$  and installed a cable that could support  $3.00 \times 10^4 \text{ N}$  without breaking. Is the elevator safe?

To determine whether the elevator is safe, we need to find out what tension the cable will experience when accelerating. If we re-draw our diagram, this time including the acceleration in the picture, we find that when we apply Newton's second law, we have a slight change.



$\sum F_y = ma_y$   
 $T - W = ma$   
 $T = W + ma$   
 $T = m(g + a)$   
 $T = (1.5 \times 10^3 \text{ kg})(9.80 \frac{\text{m}}{\text{s}^2} + 3.50 \frac{\text{m}}{\text{s}^2}) = 2.00 \times 10^4 \text{ N}$



What acceleration would the elevator have to experience in order for the cable to break? Recall that the cable can handle  $3.00 \times 10^4 \text{ N}$ .

Answer:  $10.2 \text{ m/s}^2$



What tension would the cable experience if the elevator were being accelerated at  $3.50 \text{ m/s}^2$  in the negative direction (i.e. down?) Hint: draw the diagram and make sure you get the right sign on the acceleration)

Answer:  $9.45 \times 10^3 \text{ N}$



A shopper pushes a 7.5-kg shopping cart up a  $13^\circ$  incline, as shown below. Find the magnitude of the horizontal force needed to give the cart an acceleration of  $1.41 \text{ m/s}^2$ ?

$$\sum F_x = F \cos \theta - mg \sin \theta = ma$$

$$F = \frac{m(a + g \sin \theta)}{\cos \theta} = \frac{(7.5 \text{ kg}) \left[ 1.41 \frac{\text{m}}{\text{s}^2} + \left( 9.81 \frac{\text{m}}{\text{s}^2} \right) \sin 13^\circ \right]}{\cos 13^\circ} = \boxed{28 \text{ N}}$$

