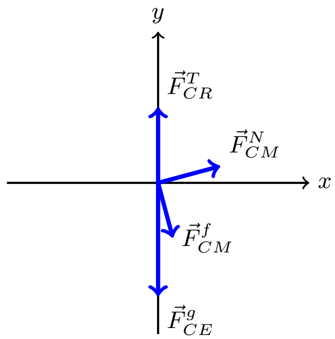
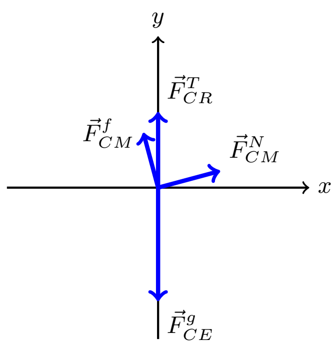
Friction is always parallel to the surface of contact, so (C) and (G) are the only possible answers. If we pick (G) and look at the free-body diagram,



we find that the x-component of the net force is positive, which would make the climber accelerate. We need friction to go in direction (C) if we want to balance the forces in the x-direction.

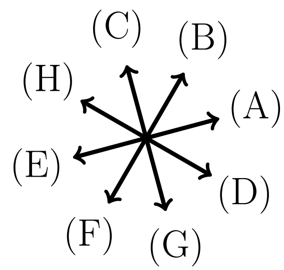


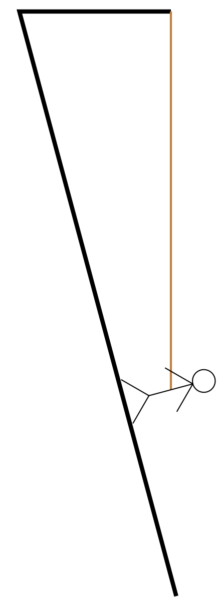
This FBD is out of scale, as the y-components of the tension, normal force, and friction clearly add to be larger than the force of gravity, and we need the x-components of friction and the normal force to be equal in magnitude to cancel out.

Lecture 8: Free-Body Diagrams

Warm-Up Activity

What direction is the force of friction in the Mountain Climbing activity from Get-Ready #5?





Free-Body Diagrams and Systems

- Choose a system.
  - Make sure you know what is internal to your system and what is external to your system.
- Identify and describe each external force:

$$\vec{F}^{\,\text{type}}_{\text{on,by}}$$

  - Say what kind of force it is.
  - Determine the object the force is being acted on.
  - Determine the object that is exerting the force.
  - Write a symbolic version of the force that includes the information above.
  - Represent all the forces acting on a single object or system using a **free-body diagram**.
    - All forces on the same free body diagram should act on the same thing (same first subscript).

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(Newton's) Laws of Motion

(1) An object in motion (or at rest) stays in motion (or at rest) unless a net external force acts on it.

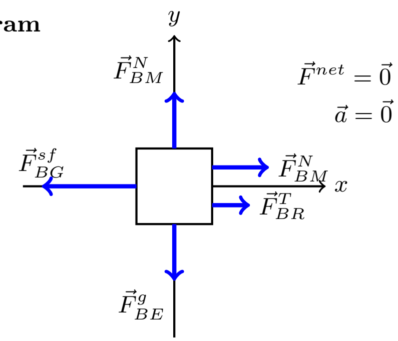
(2) The net force on an object is equal to the object's mass times its acceleration.

$$\vec{F}^{net} = m\vec{a}$$

Idenfity All Forces

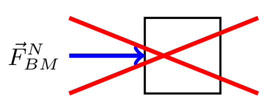
- Mike is pushing directly into the side of the box, so we need a normal force on the box by Mike: $\vec{F}^N_{BM}$.
- The box has mass, so we need a force of gravity on the box from Earth: $\vec{F}^g_{BE}$.
- The rope held by Lucas is pulling on the box (Lucas himself is not directly touching it), so we need a force of tension on the box by the rope: $\vec{F}^T_{BR}$.
- The box is sitting on the ground and not budging, so we need a normal force on the box from the ground, and a force of static friction on the box from the ground: $\vec{F}^N_{BG}$ and $\vec{F}^{sf}_{BG}$.

Free-Body Diagram

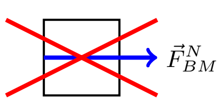


Notes

- The two vertical force vectors are equal in magnitude, so they cancel each other out.
- The force of static friction points in the direction necessary to prevent motion. The other two horizontal forces are to the left, so static friction points to the right.
- The vector for static friction is long enough to cancel both of the other horizontal forces.
- In a basic FBD, we don't care about where the force acts. We put the tail on the box and the arrow points out.
  - Using a box (instead of a dot) gives me space to offset $\vec{F}^N_{BM}$ and $\vec{F}^T_{BR}$. We don't want to overlap force vectors, as it makes the diagram unclear.
  - Some people indicate forces that push by putting the head of the arrow on the box, but this is not our convention.



  - We also don't want the arrow to overlap the interior of the box. We will do something like this when we get to rigid-body diagrams in PH 212, but for now, it is better to keep the arrows pointed away for clarity.



L8-1: Moving a Box

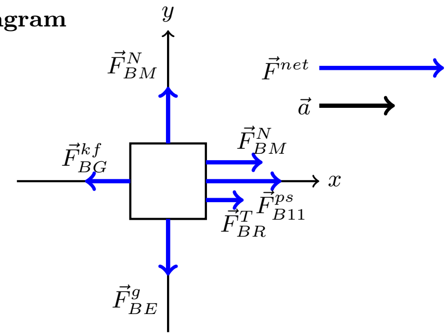
Mike and Lucas are attempting to move a box, which does not move.

- Identify all forces acting on the box.
- Draw a free-body diagram for the box.
- Indicate the acceleration.

Idenfity All Forces

- We still have most of the old forces: $\vec{F}^N_{BM}$, $\vec{F}^g_{BE}$, $\vec{F}^T_{BR}$, $\vec{F}^N_{BG}$.
- The box is sliding, so we have kinetic friction instead of static: $\vec{F}^{kf}_{BG}$.
- We need to add the psychic force exerted on the box by Eleven: $\vec{F}^{ps}_{B11}$.
- The box is sitting on the ground and not budging, so we need a normal force on the box from the ground, and a force of static friction on the box from the ground: $\vec{F}^N_{BG}$ and $\vec{F}^{sf}_{BG}$.

Free-Body Diagram



Notes

- Kinetic friction is weaker than static friction; it is harder to start an object sliding than to keep it sliding.
- $\vec{F}^{net}$ is nonzero, as the horizontal forces are no longer balanced.

Symbolic Expression

The net force is the **vector** sum of all forces on the object. Each $\vec{F}$ contains direction information, so you should not put in minus signs at this point:

$$\vec{F}^{net} = \vec{F}^N_{BG} + \vec{F}^N_{BM} + \vec{F}^T_{BR} + \vec{F}^{ps}_{B11} + \vec{F}^g_{BE} + \vec{F}^{kf}_{BG}.$$

The components of a force are scalars **with signs**, so they also contain direction information specific to their particular coordinate axes. There is no need to add minus signs when breaking Newton's 2nd law into components. At this stage, it is appropriate to drop components that you know to be zero:

$$F^{net}_x = F^N_{BM,x} + F^T_{BR,x} + F^{ps}_{B11,x} + F^{kf}_{BG,x},$$
$$F^{net}_y = F^N_{BG,y} + F^g_{BE,y}.$$

When I write the components in terms of the magnitudes of the vectors, I have to add signs, as magnitudes are always positive. In particular, $F^{kf}_{BG,x} = -F^{kf}_{BG}$, and $F^g_{BE,y} = -F^g_{BE}$. We also know that the box slides horizontally, so $a_y = 0$:

$$ma_x = F^{net}_x = F^N_{BM} + F^T_{BR} + F^{ps}_{B11} - F^{kf}_{BG},$$
$$0 = ma_y = F^{net}_y = F^N_{BG} - F^g_{BE}.$$

Therefore

$$a_x = \frac{F^N_{BM} + F^T_{BR} + F^{ps}_{B11} - F^{kf}_{BG}}{m}.$$

L8-2: Moving a Box II

El pushes the box with her mind, and it begins to speed up.

- Modify your free-body diagram.
- Indicate the acceleration.
- Write a symbolic expression for the acceleration.

Main Ideas

- Forces arise from interactions between objects.
- There are many different kinds of forces that we can analyze differently.
- Objects can only change their motion when acted upon by an external force.
- The net force on an object is equal to its mass times its acceleration.