Newton's 2nd Law: 1

PHYSICS 203, PROFS. DANIEL YAVERBAUM & MAX BEAN
JOHN JAY COLLEGE OF CRIMINAL JUSTICE, THE CUNY

Up to this point, we have dealt with forces purely ***qualitatively***. We have talked about what is pushing on what and in what direction—but we have not used any numbers. This is appropriate, since we have been dealing primarily with NI & NIII, both of which aren't really about numbers. But now we're going to play with NII, which is all about numbers: $\overrightarrow{F_{\mathrm{net}}} \equiv \sum \vec{F} = m\vec{a}$

How ***hard*** does something pull or push? The answer must be a number and like all quantities in physics, that number needs units. The SI unit for force is called a Newton, abbreviated N. ***One Newton is the force required to push one kilogram at an acceleration of 1 meter per second per second, in the absence of any other external forces.*** Which leads to our first question:

I. What is the mathematical definition of a Newton? That is, what is the algebraic expression involving seconds, meters, and kilograms that equals a Newton. Try to figure this out without looking it up. Explain your work.
Hint: Refer to NII

Ok, now that we've got that out of the way, we can safely and happily mess around with numbers and forces. We'll start with some simple warm ups. Anytime you're not sure what to do, just go back to NII.

II. 1-FORCE WARM UPS
(DON'T FORGET TO DRAW A PICTURE OF EACH PROBLEM)

A. A punter punts a football. The football weighs 1.5 kg. The football is now flying through the air, no longer in contact with the punter's foot.
   i. Assume that air resistance is negligible—i.e. assume that the football is in free fall. Therefore, what is it's ***acceleration*** (magnitude and direction)?
   ii. Now, if that's it's acceleration, use NII to compute the force that gravity must be exerting on the football.

B. A horse exerts a force of 400 N on a cart in order to pull it along a flat road at a constant acceleration of 2 m/s^2. Assume that ***all vertical forces cancel each other out.*** Assume further that "friction" and all other horizontal forces besides the horse are negligible. Compute the ***mass*** of the cart.

III. Multi-Force Warm Ups

A. An apple sits on a table (near the surface of the earth). The apple weighs 0.5 kilograms. The apple is ***not moving***.

i. Draw a picture of this situation.
ii. Draw a system schema for this situation.
iii. Draw an FBD of the apple.
iv. Write down the Newton's 3rd Law pair implied by each arrow in your FBD.
v. Compute the force that the Entire Earth exerts on the apple, through gravity. **Hint:** remember, (near the surface of the earth) the earth always tries to pull everything, regardless of its mass, at the same acceleration of 10 m/s^2. **Hint 2:** how hard ***would*** the earth have to pull in order to make the apple fall at 10 m/s^2, if the table weren't there? That's how hard it pulls.
vi. Use NII to compute the force that the table exerts on the apple.

B. A crane is lifting a bundle of scrap metal straight ***upwards*** at a constant acceleration of 3 m/s^2. The scrap metal has a mass of 450 kg.

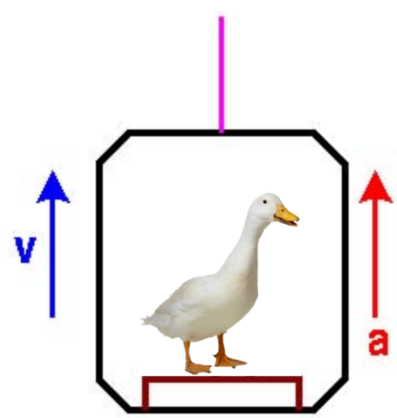
i. Draw a picture of this situation.
ii. Draw a system schema of the situation.
iii. Draw an FBD of the bundle of scrap metal.
iv. Compute the force that gravity exerts on the scrap metal.
v. Compute the force that the crane exerts on the scrap metal.

IV. The Duck and the Elevator

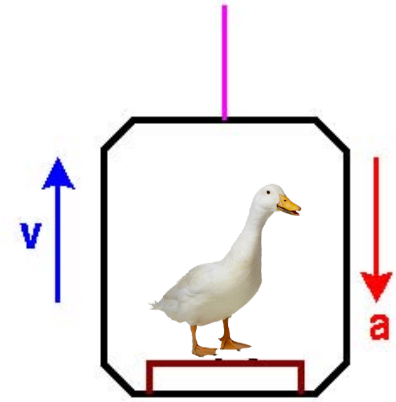
Consider the following scenario: A duck stands in an elevator. The duck has a mass of 18 kg. The elevator cage has a mass of 200 kg. At some given instant, the elevator is MOVING UP with a VELOCITY of 50 m/s relatively to the ground.

Part A: Assume that the elevator is also ACCELERATING UP at a constant rate of 15 m/s^2.

i. Draw a SYSTEM SCHEMA for this entire situation. (Hint: the duck is ***not*** touching the elevator cable, only the elevator floor.)
ii. Draw an F-B-D of the DUCK.
iii. Write out the "Action-Reaction (N-III) Pair" implied by each arrow in your FBD.
iv. Compute the magnitude of the "normal" force exerted by the floor on the duck.
v. From the perspective of the ground, how far will the duck have traveled after 7 seconds?



Part B: Now consider an alternate scenario. The situation is the same as above: the duck, the elevator, the initial velocity—BUT, instead of accelerating UP, the elevator accelerates DOWN at a rate of 15 m/s.



i. Draw an F-B-D of the DUCK.
ii. Compute the magnitude of the "normal" force exerted by the floor on the duck.
iii. Look at the sign on the normal force you computed. What direction is that force pointing? Can a normal exerted ***by*** the floor ***on*** the duck force point in this direction? If NOT, that means there IS no normal force, and the duck is not in contact with the floor.
iv. From the instant in question, how far will the duck have traveled after 7 seconds? (Assume that the elevator has no ceiling, that is, the duck can end up above the elevator.)

Part C: Now consider a third scenario. The situation is the same as the above (duck, elevator, initial velocity), but the ***acceleration*** of the elevator & duck are ***unknown***. Instead, a scale is placed under the duck. Like all scales, the scale measures the normal force between itself and whatever stands on it. The scale registers 720 N.

i. Draw an F-B-D of the DUCK.
ii. Compute the acceleration of the duck?

Part D: Reflections

i. How does the acceleration of the elevator affect the normal force on the duck?
ii. How does the velocity of the elevator affect the normal force on the duck?

Part E: Imagine that you step into an elevator and press UP. The elevator ***starts*** moving upwards. It travels for a period of time. Then it ***stops*** moving.

i. When the elevator ***is first starting to move***, what kind of acceleration does it have: upwards, downwards, or none at all?
ii. At this time, do you feel heavier, lighter, or the same as normal?
iii. When the elevator is ***in the middle of its journey***, what kind of acceleration does it have: upwards, downwards, or none at all?
iv. At this time, do you feel heavier, lighter, or the same as normal?
v. When the elevator is ***coming to a stop*** (but hasn't quite stopped yet), what kind of acceleration does it have: upwards, downwards, or none at all?
vi. At this time, do you feel heavier, lighter, or the same as normal?
vii. Do you see any connection the questions here in Part E and the questions in part D?

V. Double-Block.

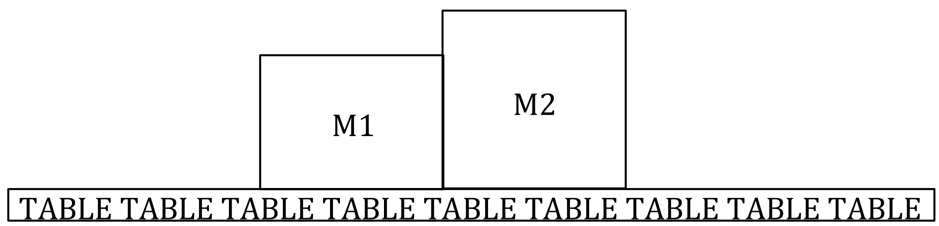
Consider the following scenario: Two blocks moving together.

Mass 1 is in horizontal contact with Mass 2.

M1 has a mass of **3 kg**. M2 has a mass of **5 kg**.

A hand exerts a purely horizontal ***leftward*** force of 10 N on M2. It just does.

The (sliding or "kinetic") friction that opposes their direction of motion (relative to the surface) exerts a force of 1.5 N on M1 and 2.5 N on M2, for a total of 4 N. For now, assume that these frictional forces are ***constant*** and ***independent*** of all other aspects of the situation. This is ***not*** actually a realistic assumption, but that's ok.



A. Draw a SYSTEM SCHEMA for this entire situation.
B. Draw an F-B-D for the 2-block system.
C. Compute the magnitude of upward ("Normal") force exerted by the table on the 2-block system.
D. Compute the ACCELERATION of the 2-block system.
E. Assuming the system starts from rest, how far will the 2-block system have traveled after 7 seconds?
F. Mass 1:
    i. Draw an FBD for M1. That is, treat M1 as one system.
    ii. Compute the magnitude of force exerted by M2 on M1.
G. Mass 2:
    i. Draw an FBD for M2.
    ii. Compute the magnitude of force exerted by M1 on M2.

H. *****EXTRA CREDIT***:** Now assume that the hand exerts a force of 10 Newtons but AT AN ANGLE: 60 degrees below the horizontal. (That is, the hand is pushing from above, pushing downwards, forming a 60 degree angle with the "x axis.") All other values remain the same as above.
    i. Given this new assumption, re-answer questions A-G (above).
    Hint: Forces are vectors. They can be broken up into components, just like any other kind of vector.