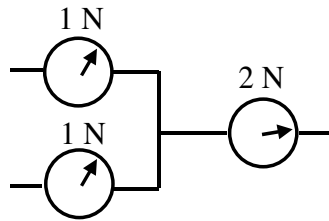


Dynamics: Newton's Laws

Dynamics refers to the connection between forces and motion. (It answers the “why” of kinematics’ “what”...) The key concept is **force**, which is nothing more than any kind of physical push or pull. Force is a vector, it has size and direction. We’ll want to quantify and compare forces: the “standard metric pull” will be called 1 Newton, or 1N. (We’ll figure out how big this standard should be, soon)

Once you’ve rigged a device to measure pull (we’ll see some shortly), you can calibrate other devices, e.g. like this:

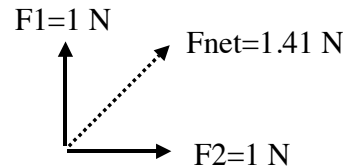


Force *combine* (or *add*) like vectors.

If many people tug on one object, the NET or total resulting force is

$$\vec{F}_{\text{net}} = \vec{F}_{\text{total}} = \sum \vec{F}_i = \vec{F}_1 + \vec{F}_2 + \dots \quad (\text{Different notations, same thing.})$$

Example: if $F_1=F_2=1$ N, and they’re at right angles to one another, the vector sum (use the Pythagorean theorem) gives $F_{\text{net}} = \text{Sqrt}[2]* 1\text{N} = 1.41$ N



Forces are pushes or pulls. When you **APPLY** forces to objects, the objects respond by accelerating. No force at all means **NO** acceleration at all. This is **NOT** obvious to many people! Aristotle (and still many people today) thinks you must apply a net force to **KEEP** an object moving along steadily. But **NO**, you don’t. Experimentally, that’s **100%** incorrect.

Steady motion means no acceleration: no net force is required!

A correct description of nature was discovered by Isaac Newton (1642-1727, England). Here's a simplified version of Newton's first law of motion (N-I for short)

If you leave an object alone (no pushes or pulls on it, i.e. no forces applied), then it will not accelerate.

“Not accelerating” means $\mathbf{a}=0$, or $d\mathbf{v}/dt=0$, i.e. $\mathbf{v}=\text{constant}$. (Same speed, same direction). An object at rest will remain at rest if no force acts on it.


An object in motion remains with the same motion (same direction, same speed) if no force acts on it.

(Another name for N-I is “the law of inertia”, because inertia refers to the tendency of objects not to want to change...)

A more careful (and accurate, and useful) statement of N-I adds a single new idea:

N-I: If there is no net force on an object, the object will not accelerate.

I added the word “net”, that's the key. There CAN be forces on the object, but as long as they add up (vectorially) to zero, then the object will still have $\mathbf{a}=0$.

 If a cart is pushed forward by you, and friction pushes backwards on it, and those two balance out ($\mathbf{F}_{\text{you}} = -\mathbf{F}_{\text{friction}}$), then $\mathbf{F}_{\text{net}}=0$, and the object moves steadily.

Of course, you will only NOTICE your OWN force, you may not be even aware of the existence of friction. That's why people may think there *needs* to be a net force to keep it moving steadily - they haven't really noticed the significance of friction. So, people used to think “Force causes motion”, and this is WRONG! (Think of a glider on an air track, or an asteroid cruising forever in deep space. NO force is required for motion). The correct statement is “Force causes CHANGE in motion”.

Newton discovered *how* force is related to change in motion. It comes, ultimately, from *experiment*, from observing how the world works. E.g., suppose you push a cart on an air track (no friction) with a fixed, calibrated force. What do you observe? The cart accelerates in the direction of the force. If you DOUBLE the force, acceleration doubles. Suppose you go to an air table - you can measure acceleration in 2-D, or 3-D, and the above still holds.

Conclusion: acceleration is proportional to force, or $\mathbf{a} \propto \mathbf{F}$.

This is a vector equation: the direction of \mathbf{a} is the same as the direction of \mathbf{F} .

(Note: direction of \mathbf{a} isn't the same as direction of \mathbf{v} : acceleration is CHANGE in \mathbf{v} !)

What if you keep the force fixed, but change the object's mass? (E.g., double it up: the resulting acceleration is halved) Acceleration is *inversely* proportional to mass. Putting these together (and after observing that acceleration depends on nothing else besides F and m) you find Newton's second law, or "N-II" for short: $\vec{a} = \vec{\mathbf{F}}_{\text{net}} / m$, or, if you prefer

N-II: $\vec{\mathbf{F}}_{\text{net}} = m\vec{a}$
--

This equation looks so simple, but it contains the essence of most of classical physics. It will take a lot of practice to get to understand and use this equation to solve problems.

Initial comments:

- F_{net} means the vector sum of ALL forces acting on the object. You MUST identify and sum them all up. It won't be true that $\mathbf{a} = \mathbf{F}/m$, if \mathbf{F} is only one of many forces acting.

(E.g. with that cart example, if you forget about friction, and only included YOUR force, you would incorrectly conclude that the cart must accelerate)

- What is “mass”, m , in that equation? It's how much “stuff” the object contains. Mass is a scalar, not a vector. It's a quantitative measure of the inertia of the object. (Freight trains are more massive than mosquitoes, they contain more “stuff”, have more inertia.)

Mass is formally measured by comparing to a standard kg stored in a vault in France.

My mass is about 55 kg.

My Honda's mass is about 1000 kg.

A small cart on the air track has $m = .1$ kg.

In the grocery store, people are sloppy (or confused), and mix up mass and weight.

They say “the sugar weighs 1 kg”. This is wrong! Mass and weight are different, we'll discuss this soon.

- Units of force are $[F] = [m][a] = \text{kg} * \text{m/s}^2$. We define $1 \text{ N} = 1 \text{ kg m/s}^2$.

1 Newton is the force required to accelerate (any!) object of mass 1 kg by 1 m/s^2 .

1 N is not a lot of force. It's like a soft “finger touch”.

- All of the above (N-I and N-II) are true only in “inertial reference frames”, which means frames that don’t accelerate. Inside a train or plane *moving* with steady \mathbf{v} is fine, that’s an inertial reference frame and Newton’s laws hold. But, inside an *accelerating* rocket (say), which is NOT an inertial reference frame (it’s “non-inertial”), you’ll see things spontaneously accelerate without any apparent force acting, a violation of N-I...

- Newton defined a quantity, momentum, $\mathbf{p} = m\mathbf{v}$. (We’ll talk about it more later.)

N-II can then be written $\vec{\mathbf{F}}_{\text{net}} = \frac{d\vec{\mathbf{p}}}{dt}$. (proof below) *This* is really the right equation

to use in *all* cases (e.g. when mass is changing along with velocity, like a rocket spewing out fuel). For now, we’ll stick to fixed masses, and then you can reliably use $F=ma$.

Proof of equivalence when m is constant:

$$\begin{aligned}\vec{\mathbf{F}}_{\text{net}} &= m\vec{\mathbf{a}} \\ &= m \frac{d\vec{\mathbf{v}}}{dt} = \frac{d(m\vec{\mathbf{v}})}{dt} = \frac{d\vec{\mathbf{p}}}{dt}\end{aligned}$$

(If m is constant, you can slide it inside the derivative in the 2nd line. If m is varying with time, $F=ma$ is *wrong*, and $F=dp/dt$ is the correct equation to use.)

- N-II is a vector equation. Remember what that means, it’s a shorthand:

x component: $F_{\text{net},x} = \sum F_{i,x} = m a_x$

y component: $F_{\text{net},y} = \sum F_{i,y} = m a_y$

When you work 2-D problems, you’ll have an “x-component of N-II” eqn, and a separate “y-component of N-II” eqn, TWO eqns to use!

- The LEFT side of N-II is forces: physical pushes and pulls.

The RIGHT side of N-II is acceleration: a description of the resulting change in motion.

The “equal sign” does NOT mean that acceleration is a force. (It’s not!)

Acceleration simply describes change in velocity. The “equal sign” is almost magic: it says that the sum of forces will always agree, quantitatively, with the observed acceleration. It’s “cause and effect” on the left and right sides. Try to THINK about $F=ma$ in this way: left side is FORCES, right side is observed change in MOTION.

- Types of forces: gravity; friction; tension (the name for the pull of a rope or cord); contact (e.g., your hand pushing something, or a table pushing against an object, holding it up). The latter is also sometimes called the “normal” force between surfaces. (Normal in the mathematical sense of “perpendicular”, because contact forces are perpendicular to the surfaces) And many more: electrical, magnetic,... You don’t need a person (or animal) to produce a force, nor do you need a motor. The table can apply a force to a book sitting on it just fine.

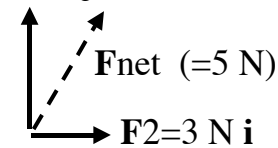
There are only 4 fundamental forces of nature: gravity, electromagnetism, “weak nuclear”, and “strong nuclear”. All others, like e.g. friction, arise from these (friction is electromagnetic in origin).

Example: I push an air cart ($m=0.1$ kg) with a steady $\mathbf{F}=5$ N to the right. What is \mathbf{a} ?

Answer: Define $+x$ to be to the right, so $\mathbf{a}=\mathbf{F}/m = (5 \text{ N}) \mathbf{i} / (0.1 \text{ kg}) = 50 \text{ N/kg } \mathbf{i}$.

(The units are o.k., because $1 \text{ N/kg} = 1 \text{ m/s}^2$)

Example: 2 people push a hockey puck ($m=0.1$ kg) with forces of 3 N to the right, and 4 N forward, respectively. What is the resulting \mathbf{a} ?



Mathematically, $\mathbf{a} = \mathbf{F}/m = (3\mathbf{i} + 4\mathbf{j}) \text{ N} / 0.1 \text{ kg}$
 $= (30\mathbf{i} + 40\mathbf{j}) \text{ m/s}^2$.

The magnitude of this \mathbf{a} is $\text{Sqrt}[30^2+40^2] = 50 \text{ m/s}^2$.

This last result can also be obtained by noting, from the geometry of the picture, that $|\mathbf{F}_{\text{net}}| = 5\text{N}$ (Slide F1 over to the right, you have a 3-4-5 triangle) so $|\mathbf{a}| = |\mathbf{F}|/m = 5\text{N}/0.1 \text{ kg} = 50 \text{ m/s}^2$, and the angle of $\mathbf{a} = 53$ degrees from horizontal. Many more such examples in the text. (Look at them, work them out for yourself.)

Summary: $\mathbf{F}_{\text{net}} = m\mathbf{a}$ contains a *lot* of physics. E.g.

a) Motion is observed (or described to you). From Ch. 2 through 4, this means you are being given acceleration. N-II then lets you *deduce* what \mathbf{F}_{net} is, and you can figure out something about an (unknown) force. (This is how we learn about new forces in nature)

b) Forces are measured (or described to you) - you may have to sum up a bunch of them - and then N-II lets you *deduce* what \mathbf{a} is. From Ch. 2 through 4, knowing \mathbf{a} (especially if it turns out constant, or centripetal) quickly allows you to say what the resulting motion will be. Knowing forces lets you predict the motion of things.

Mass vs. Weight.

(We've discussed mass above: a scalar quantity, measured in kilograms)

Weight is *defined* in physics to be the force of gravity on some object.

It's the FORCE, it's a vector. $\mathbf{W} = \mathbf{F}_{\text{grav}}$.

Any object (near earth) subject only to gravity will accelerate with $a=g$, down.

Since $F=ma$ this tells us $\mathbf{F}_{\text{grav}} = mg$ down.

$\boxed{\mathbf{W} = mg \text{ (down)}}$, for any object near the earth.

It's a force vector: units are N. (not kg!)

A 1 kg mass weighs $m*g = (1\text{kg})*(9.8 \text{ m/s}^2) = 9.8 \text{ N}$.

In the British system, this is about 2.2 lbs. A pound IS a [non-metric] unit of force,

NOT a unit of mass! The British unit of mass is (yes!) a slug = 14.6 kg.

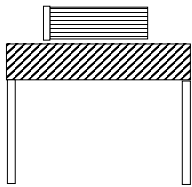
Weight is proportional to mass, but *not* the same. You weigh less (by a factor of about 6) on the moon - but your mass there is unchanged from here on earth. In deep space, you are weightless, but your mass is still unchanged. You still have *inertia* in space! In deep space, an astronaut would have a hard time "juggling" 1000 kg lead bricks. Yes, they'd be "weightless", floating around the cabin, but $F=ma$, their large mass means that when you push them, they barely accelerate!

We'll talk more about weight at the end of this chapter. One subtle point - astronauts in the shuttle are *not* in deep space. They're only 200 km from earth, closer than Grand Junction is from Denver. The acceleration of gravity up there is about $0.93*g$, almost the same as here. So why do they float and appear to be "weightless"?

Because they're in free fall. Like people in a freely falling elevator, who ALSO

appear to be weightless (until the elevator hits bottom!) The only difference is the space shuttle, while falling, has a sideways motion that makes it “miss” the earth, so they never hit ground. (More on this topic at the end of this chapter)

Example: A book sits still on the table. What forces act on it?



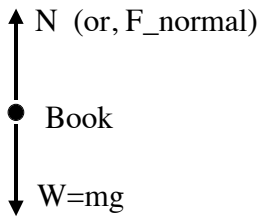
Certainly gravity acts on it (mg down). But is that all?

It's sitting there, so $\mathbf{v}=\text{constant}$, which means $\mathbf{a}=0$. N-II tells us that $\mathbf{F}_{\text{net}} = m\mathbf{a}=0\dots$ So there **MUST** be some other force acting.

And of course there is: the table applies an upward force on the book, holding it up.

How big is this upward force, called a contact or “normal” force?

Let's draw a picture containing only the forces *on the book*.



N-II says $\mathbf{F}_{\text{net}} = 0$, in other words $\mathbf{N} + \mathbf{W} = 0$.

We must have $\mathbf{N} = -\mathbf{W}$, which means

$N=mg$ (up). The table pushes up.

Tables are like *springs*, they get squished a little when something pushes down on them, and they push right back up. N-II teaches us in this problem that $N= mg$ up, but this is just the answer *in this problem* - it's NOT a law of nature, or a formula to memorize!

The 2nd picture in that last problem is called a “free body diagram” or “force diagram” (FD for short). Drawing FD’s are KEY to solving many physics problems, and to *understanding* what’s going on. There are certain conventions in such FD’s:

- Isolate ONE object to consider. (In the previous problem, don’t try to draw a FD for the book AND the table. Pick one of them only. I picked the book.)
- Think of all (and ONLY) the physical pushes/pulls that act *directly* on the object
- Draw arrows to show direction of forces. Label the arrows with their magnitudes. (The arrow shows the direction, so I did NOT label the weight “-mg” there. The minus sign would just confuse me. The arrow clearly indicates the force of gravity is down.)
- The FD is for forces! You can add “mass”, and maybe some key geometrical facts, like angles of forces. Try not to put anything else in the picture, *especially* not arrows for velocity or acceleration. The picture is an abstraction, no artistic skills are required. Don’t try to “draw” the object, consider it to be a “dot” or point....
- Don’t draw “F_{net}” in your picture. You’ll compute it later: F_{net} just *means* the sum of all the F’s in your picture. (Similarly, DON’T draw **ma**. That’s not a force!)

Example: Suppose that previous problem had been about a glider on an air track, sliding to the right with constant velocity $\mathbf{v0}$. The FD would have been EXACTLY the same! The forces are still gravity (down) and normal (or contact) force up.

Frictionless surfaces like air tracks can't apply sideways forces (they're frictionless!)

So the FD in this case is the SAME, and the conclusion is the same - a glider on a horizontal air track also feels an upward normal force = mg.

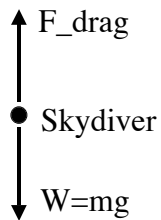
Example: A skydiver has reached terminal velocity, about 140 mi/hr (60 m/s) What can you conclude about the "drag force" of air friction on her?

Answer: We haven't learned about drag forces yet. So, how could I know?

N-II tells me!

You only need to know that "terminal velocity" means "top speed". Skydivers don't keep accelerating forever, because of air friction. If $v=140$ mi/hr (= constant) then $a=dv/dt = 0$. v isn't CHANGING any more once you've reached terminal...

Draw the FD:



There are only two physical forces acting. Weight and air friction.

(The velocity is down, but doesn't belong in this picture!)

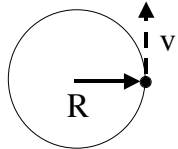
By N-II, $\mathbf{F}_{net} = \mathbf{F}_{drag} + \mathbf{W} = \mathbf{ma}$

Since we just said $\mathbf{a}=0$, that means $\mathbf{F}_{drag} = -\mathbf{W}$. In other words, it's mg, up.

Again, that's not a law of physics, it's just the answer to this particular problem.

Example: A rock is twirled horizontally on the end of a string at constant speed, v .

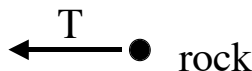
Neglect gravity. What is the tension in the string?



This is NOT a FD. It's just a sketch of the problem. Looking at the sketch, I can see that this is uniform circular motion, and we know (from Ch. 4) that the object is accelerating towards the center, with

magnitude $a = v^2/R$. (centripetal acceleration formula)

Now we can draw the FD:



That's IT! If we neglect gravity, the ONLY

force on the rock is the tension, T , of the string. (Don't confuse the symbol "T" for tension with "T" for period. We only have 26 letters to work with, sooner or later we had to duplicate symbols like this)

Strings can only pull (they can't push), so the tension must be pointing along the string, towards the center, as shown.

In this problem, N-II says $\mathbf{F}_{net} = m\mathbf{a}$. The left hand side is just \mathbf{T} , the right hand side is $m v^2/R$ (towards the left), and we're done. That's the tension in the string.

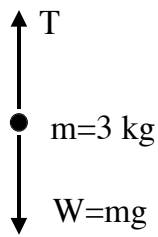
Example: A 3 kg mass hangs on a rope. It is accelerating *down*, with $\mathbf{a} = -5 \mathbf{j} \text{ m/s}^2$.

(Negative acceleration means the rope might be lowering it faster and faster, or it might be *going* up, but slowing down.)

Question: what is the force (tension) in the rope?

Answer: You might be tempted to say: $F=ma$, we want F , a is given. Isn't it that easy?

No - remember, it's $\mathbf{F}_{net}=m\mathbf{a}$! You *really* need to draw a FD:



There are *two* forces on the mass. Tension (up, it's "hanging" on the rope, so the rope must be pulling it up) and Weight (down)

That's IT. No other physical forces acting.

Now, N-II says $\mathbf{F}_{\text{net}} = m\mathbf{a}$

$\uparrow +y$ (From the problem statement itself, I've implicitly chosen "up" to be +y.)

The y-component" of N-II is where the action is (nothing is going on in the x direction)

$F_{\text{net},y} = m \cdot a_y$. Since \mathbf{a} is in the $-\mathbf{j}$ direction, we just read off $a_y = (-5 \text{ m/s}^2)$

The left side of N-II comes from the sum of forces in the FD.

All signs are given by the *direction* of the arrows:

\mathbf{T} is up (that's the +y direction) so $T_y = +T$.

\mathbf{W} is down (that's the -y direction) so $W_y = -mg$.

Combining, $F_{\text{net},y} = T - mg = m \cdot a_y = m \cdot (-5 \text{ m/s}^2)$ or (solving for T)

$T = mg + m a_y = m(10 \text{ m/s}^2 - 5 \text{ m/s}^2) = +3 \text{ kg} \cdot (5 \text{ m/s}^2) = +15 \text{ N}$.

Compare this with the weight, which is $mg = 30 \text{ N}$.

The tension is NOT mg , it's less. That makes sense if you think about it: if T was equal to mg , there'd be ZERO net force \Rightarrow no acceleration at all.

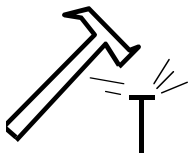
Since it accelerates down, there MUST be a net downward force. Gravity is partly (but not totally) cancelled by the tension, leaving behind a net downward pull.

Newton's Third Law: Newton came up with one more important law about forces:

N-III: If an object exerts a force on another object, the other object always exerts a force right back on the first, equally, but opposite in direction.

Sometimes written more concisely $\vec{F}_{\text{by A on B}} = -\vec{F}_{\text{by B on A}}$.

The two forces, \vec{F}_{AB} and \vec{F}_{BA} are acting on *different* objects! Labeling forces like this is awkward, but useful. Such pairs of forces are sometimes called an “action-reaction pair”.



E.g., a hammer hits a nail. This picture is *not* a FD - you must pick ONE and only one object to focus on for a FD.

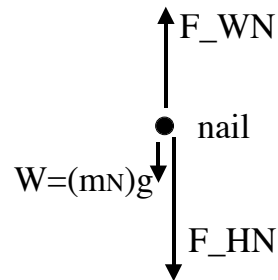
Let's draw one for the nail, and then separately for the hammer.

The nail feels many forces. I show a few important ones:

F_{HN} = Force by the Hammer on the Nail. (down)

F_{WN} = Force (of friction) by the Wood on the Nail.
(up)

W = Weight of nail (formally: Force of gravity by the Earth on the Nail)

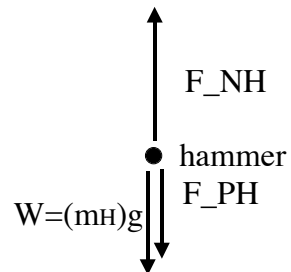


The hammer also feels many forces. E.g.:

F_{NH} = Force by the Nail on the Hammer.

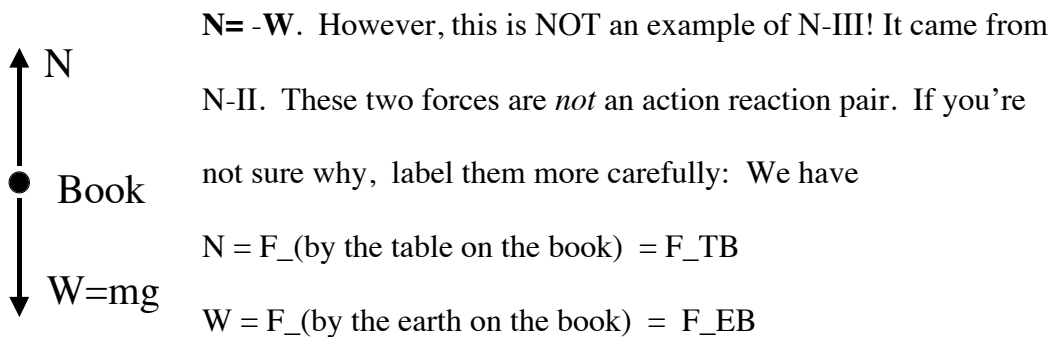
F_{PH} = Force by the person on the hammer (down)

W = Weight of hammer



N-III tells us only one key thing here: $F_{NH} = -F_{HN}$. The force by the nail on the hammer is *equal* and opposite the force of the hammer on the nail! So, the nail pushes the hammer UP, which is correct- the hammer is being STOPPED (or slowed) by the nail, it does have an UPWARD acceleration, it's the nail that's doing this.

Example: Go back to the example of a book sitting on the table (p.5-8) Recall:



Clearly not of the form “ F_{AB} and F_{BA} ”.

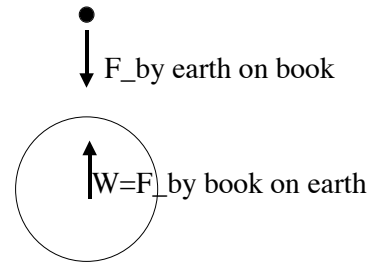
But N-III says there are ALWAYS action reaction pairs. So, where is the N-III “partner” to, say, N ? Use the labels to help find out! That would be $F_{\text{(by the book on the table)}}$.

It belongs in *another force diagram* - the one for the table. That's why we don't see it in the picture above. It's the *downward* force of the book on the table. (Which makes sense, a heavy book will push down on the table it's sitting on, right?)

How about the N-III partner to W? Where is that?

That would have to be $F_{\text{by the book on the earth}}$

What's that? Is the book really pulling UP on the earth EQUALLY hard as the earth pulls down on it?



Yes indeed!

So, why doesn't the earth "fall up" towards the book, rather than the other way around?

Why, it does! Remember, $F=ma$, so the huge mass of the earth results in an immeasurably tiny acceleration. But it's real, and HAS been seen by astronomers when the object was a little bigger than a book (like, e.g. a planet. You can see the stars "falling" towards a circling planet as well as the planet falling towards the star. Both forces are equal and opposite.)

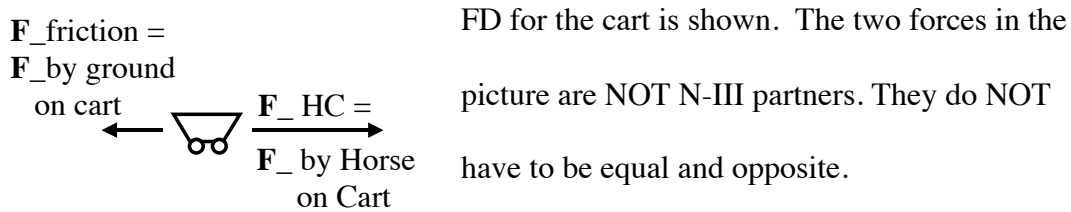
PUZZLE A horse is asked to pull a cart. The horse, having read Newton's Principia, says "If I pull on the cart, it will surely pull right back on me, with an equal but opposite force. I won't *ever* be able to make the cart move, since the forces will always balance. So why even bother?..." At which point the horse nibbles on some grass.

Is the horse correct? How do carts ever get pulled then??

The first statement of the horse is quite correct, but fortunately, the conclusion is *not*.

Whether the cart moves depends only on the sum of forces acting ON THE CART.

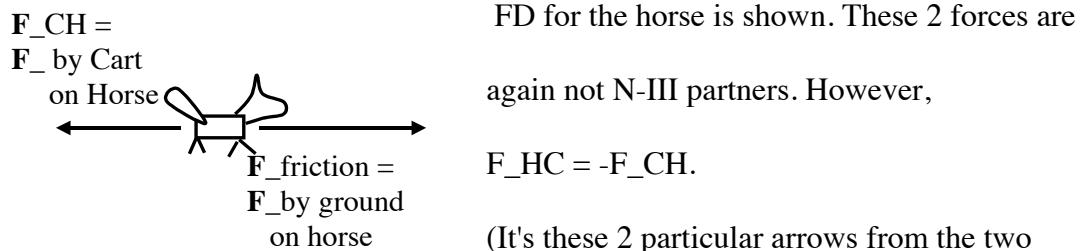
Forces acting on the horse are irrelevant if you're asking about the motion of the cart! (N-III partners act on DIFFERENT objects.)



(If $F_{HC} > F_{GC}$, then N-II says the cart accelerates to the right, which you want.

Just make sure friction isn't too big, shouldn't be a problem)

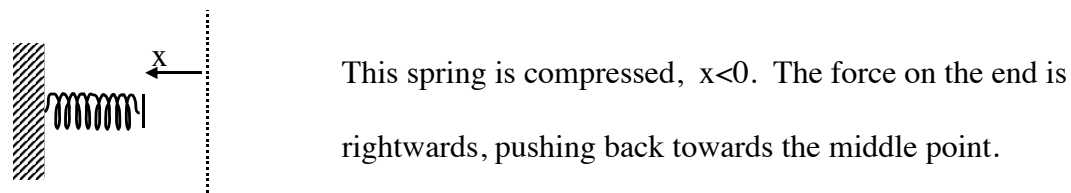
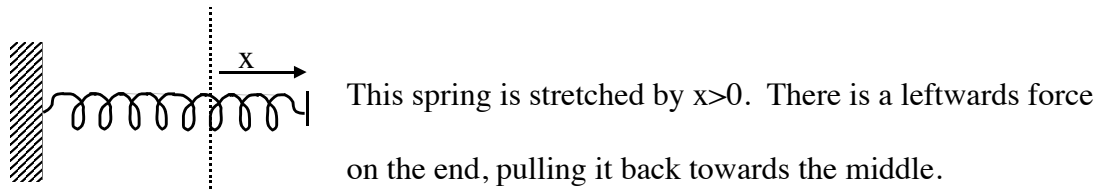
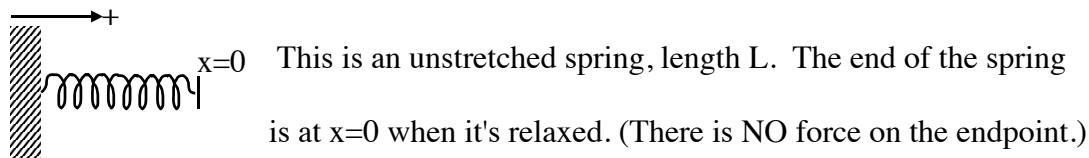
Where is the N-III partner the horse was talking about? On the horse!



(It's these 2 particular arrows from the two different pictures are equal and opposite. That's all...)

Whether the HORSE can move depends on $F_{\text{friction by ground on horse}}$. (If the horse stands on ice, it won't be able to move the cart!) But there's no reason why a strong horse can't make $F_{GH} > F_{HC}$

SPRINGS: Another very common natural force is a “spring force”. We will generally consider “ideal” springs in this course. They act like this:



Hooke's Law is an empirical (which means approximate, based on experiments) formula that says the force of the spring is proportional to the stretch, $F \sim |x|$. If you stretch it twice as far, the force is twice as strong. This formula can be written as $\boxed{\mathbf{F} = -k \mathbf{x}}$. The minus sign says the direction is opposite the position. ($x > 0$ means $F < 0$, just like in the pictures above.)

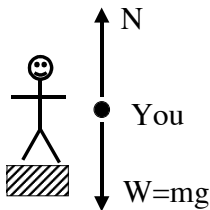
“ k ” is the “spring constant”. It depends on the material and design of the spring. It has units [N/m]. Typical “ k ”s might be 100's of N/m.

A bigger “ k ” means you have a stiffer spring (lots of force for a little stretch)

Hooke's law is NOT fundamental, like $F=ma$, or even like $F=mg$. (Real springs will deform if you stretch them too much.) But it's a good approximation and idealization, we'll use it frequently. (Springs let you *measure* forces in the lab easily, because x is so easy to measure.)

Return to Weight, and Apparent Weight: When you step on a scale, it pushes *up* on you (otherwise you'd fall through it to the floor). By N-III, you push equally hard *down* on it. The scale reading tells you the size of this push. So technically, it is NOT telling you your weight (F_{grav} on you), it is telling you the Normal force of the scale up on you.

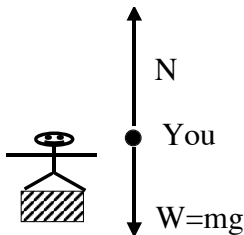
We call the scale reading your apparent weight.



Ordinarily, you're at rest: $a=0$. So N-II says $F_{\text{net}} = ma = 0$, or (defining "up" to be "+y"), $N - mg = 0$.

The scale reads N . This is the SAME as your weight, by N-II.

Suppose instead you and the scale are in an elevator, accelerating UP at $a=+0.5 g$.



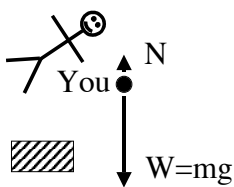
The FD is the same (except N doesn't have to be the same length as it was before. N always adjusts!)

N-II: $F_{\text{net},y} = ma_y = m*(+0.5 g)$

$N - mg = +0.5 mg$, or $N = 1.5 mg$. The scale reads 50% heavy!

You FEEL heavy too, the ground (and scale) are pushing up harder than usual on you (to ensure that you accelerate up at $0.5g$)

Suppose now that the elevator cable is cut, you're accelerating DOWN at $a=-g$.



The FD is STILL the same. (except the N doesn't have to be the same length as it was before). Gravity is still pulling you down.

N-II: $F_{\text{net},y} = ma_y = m*(-g)$,

$N - mg = - mg$, or $N = 0$. The scale reads zero. You are floating! You're in freefall.

In free-fall, if you drop something, it too is freely falling, and appears to float. It's like you're an astronaut. This IS what's going on in the space shuttle - it's not that gravity is gone up there, but that the shuttle and its occupants are freely falling towards the earth.