Physics Basics, Part I

Units

Laws of Motion

Units of Measurement

- Physics forms a link between the physical world (concepts) and the mathematical world (quantitative)
- This inevitably involves *measurements*
  - Measurements inevitably involve *units*
- We'll stick to MKS (SI) units in this course
  - MKS: meters; kilograms; seconds
  - As opposed to cgs: centimeter; gram; seconds
- Distance in meters (m)
  - 1 meter is close to 40 inches
- Mass in kilograms (kg)
  - 1 kg is about 2.2 pounds
- Time in seconds (s)

Secondary Units

- Units can be combined in a variety of ways to form complex units, many of which have their own names/symbols

quantity	**formulation**	**Complex unit**	**For short**
velocity	dist/time	m/s	—
acceleration	velocity/time	m/s^2 = m/s/s = m/s per s	—
force	F=ma	$kg \cdot m/s^2$	Newton (N)
work/energy	W=F·d	$kg \cdot m^2/s^2$	Joule (J = N·m)
power	energy/time	$kg \cdot m^2/s^3$	Watt (W = J/s)
frequency	cycles/second	1/s	Hertz (Hz)
pressure	force/area	$kg/m \cdot s^2$	Pascals (Pa = N/m^2)

Electrical Units

- We'll deal a lot with electrical phenomena in this course, with its own (but related) set of units:

quantity	**formulation**	**units**	**for short**
charge	*I*	Coulombs	C
current	charge/time	C/s	Amps (A)
voltage	$V = IR$	V	Volts (V)
resistance	$R = V/I$	volts/amp	Ohms (Ω)
power	$P = VI = I^2R = V^2/R$	volt-amps	Watts (W = J/s)
electric field	voltage/distance	V/m	—

Mass and Inertia

- Mass is how hard it is to get something to move
  - Intimately related to the idea of **inertia**
  - Effectively how many protons and neutrons in the thing
  - Distinct from weight, which relates to gravity
    - the same mass weighs different amounts on different planets
- Inertia relates to Newton's first law of motion:

  an object in motion will remain in that state of motion unless acted on by an outside force
- This applies to being at rest as well as being in a state of motion
  - motion relative to *what*

Newton's Second Law of Motion

- Okay, what about when there *is* an outside force?
  - outside: not coming from within the body; an external agent
  - force: something that pushes or pulls
- Then we have Newton's Second Law of Motion:

$$F = ma$$

- Great: now we have to talk about acceleration
  - the rabbit hole gets deeper
  - but first let's give some examples of force…

Examples of Force

- Examples:
  - gravity exerts a downward force on you
  - the floor exerts an upward force on a ball during its bounce
  - a car seat exerts a forward force on your body when you accelerate forward from a stop
  - the seat you're sitting in now is exerting an upward force on you (can you feel it?)
  - you exert a sideways force on a couch that you slide across the floor
  - a string exerts a centrally-directed (centripetal) force on a rock at the end of a string that you're twirling over your head
  - the expanding gas in your car's cylinder exerts a force against the piston
- Note the syntax: Agent exerts directed force on recipient

Velocity and Acceleration

- Velocity is a speed and associated direction
  - 10 m/s toward the north
  - 50 m/s straight upward
- Acceleration is *any* change in velocity
  - either in speed OR direction
- Acceleration measured as *rate of change* of velocity
  - velocity is expressed in meters per second (m/s)
  - acceleration is meters per second *per second*
  - expressed as m/s^2 (meters per second-squared)

The Force-Acceleration Connection

- Whenever there is a *net* force, there *will* be an acceleration
  - A ball thrown into the air has the force of gravity operating on it, so its velocity continuously changes, resulting in a curved path
  - When you step on the gas, a forward force acts on your car, making it speed up
  - The force of gravity attracts the earth toward the sun. This has the effect of changing the direction of earth's velocity, wrapping it into a circle around the sun (centripetal force)
  - A car, slamming into the side of another car already moving forward, will exert a sideways force, changing the traveling car's direction of motion
  - When a bat hits a ball, the large momentary force results in a large acceleration of the ball as long as contact is maintained

All Forces Great and Small

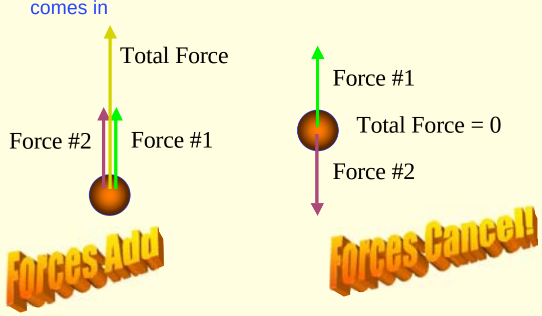
- The relation, $F = ma$, tells us more than the fact that force and acceleration go together
  - the relation is *quantitative*, and depends on mass
- For the *same* applied *force*:
  - a small mass will have a greater acceleration
  - a large mass will have a smaller acceleration

Force = mass×acceleration OR Force = mass×acceleration

- If you want the same acceleration, a smaller mass requires a smaller force, etc.
  - this then relates mass and inertia in an intimate way:
  - how hard is it to get an object moving?

Hold On a Second…

- I've got forces acting on me right now, but I'm not accelerating *anywhere*
  - very perceptive, and this is where the concept of *net* force comes in

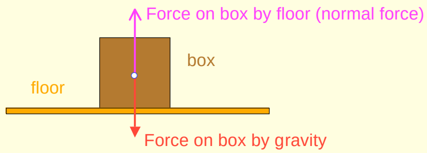


Examples of Zero Net Force

- Sitting in your seat, gravity is pulling down on you, but the seat reacts by pushing up on you. The forces cancel, so there is no net acceleration
- Pushing against a huge crate, the force of friction from the floor opposes this push, resulting in no net force and thus no acceleration

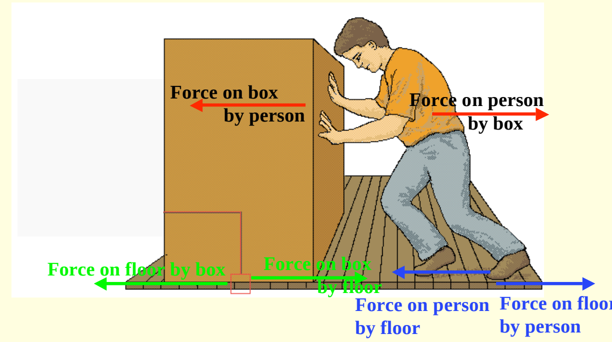
Newton’s Third Law

- For every force, there is an equal and opposite force
  - every “action” has a “back-reaction”
  - these are precisely equal and precisely opposite



- You can’t push without being pushed back just as hard
  - in tug-of-war, each side experiences the same force (opposite direction)
  - when you push on a brick wall, it pushes back on you!

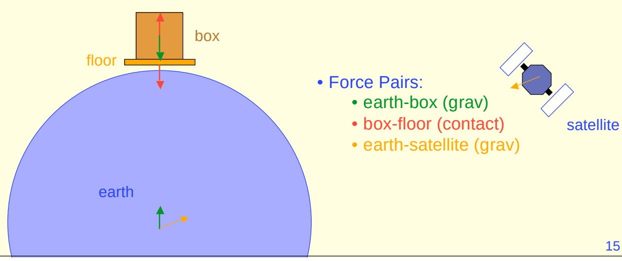
Force Pairs Illustrated



Not shown are the forces of gravity and the associated floor forces

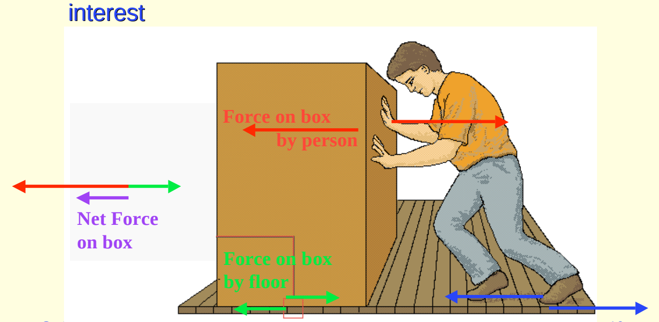
Wait: We cheated two slides back…

- When we drew the box and floor, with the “normal” force from the floor canceling the force of gravity, these weren’t strictly force pairs
  - but these are the two canceling forces on the box that result in zero acceleration of the box
- The real pairs have to involve the earth:



Don’t all forces then cancel?

- How does anything ever move (accelerate) if every force has an opposing pair?
- The important thing is the net force on the object of interest



Gravity

- One of the most apparent forces in our daily experience is gravity
- Gravity is the *mutual attraction* of mass
  - it's always attractive, never repulsive
  - all particles in the earth attract all particles in your body
  - net effect (force) is effectively toward the center of the earth
- Follows force law elucidated by Newton:

$$F_{grav} = GMm/r^2$$

  - where M is mass of earth, m is mass of you (or object of interest), and r is distance (separation) between object and earth's center. G is just a constant: 6.67×10^{-11} in MKS units
  - Note that since $F = ma$, we can say

$$a_{grav} = GM/r^2 \quad \text{is the acceleration due to gravity}$$

Gravity on earth's surface

- The product, GM, for earth, is 3.986×10^{14} m^3/s^2
  - so a_{grav} evaluates to 9.8 m/s^2 on earth's surface (r = radius of earth = 6,378 km)
- Bottom line: falling objects accelerate at 9.8 m/s^2 on the surface of the earth
  - downward velocity changes by about 10 m/s with each passing second
- This also means that to support a 1 kg book against the pull of gravity, one must exert $F = ma$ = (1kg)·(10m/s^2) = 10 Newtons of force
  - this is the object's *weight: mg*
- Support for the book is just the "normal" force required to keep the book from accelerating
  - in other words: to make the net force on the book zero

Pressure, Density

- Pressure is force per unit area
  - measured in N/m^2, or Pascals (Pa)
  - the pressure of the atmosphere at sea level is about 10^5 = 100,000 Pa (about 14.6 pounds per square inch—psi)
    - pounds are also a unit of force, like the Newton
- Density is mass per volume
  - measured in kg/m^3
  - water is 1000 kg/m^3 (same as 1 g/cm^3 in cgs units)
  - air is about 1.3 kg/m^3
  - rock is 3300 kg/m^3
  - gold is about 19,300 kg/m^3

Announcements/Assignments

- Next up:
  - energy in its myriad forms
  - a simple model for molecules/lattices
  - electrons, charge, current, electric fields
- Assignments:
  - Read Chapter 1 of book
    - You can skip sections on velocity, position of falling balls, as well as section on projectile motion (pp. 15–21)
  - Read Chapter 2: pp. 54–59, 61–62, 71–72
  - Transmitters will start counting for credit Tuesday 4/11
  - First HW will be due Thursday 4/13
  - First Q/O due Friday, 4/14 by 6PM via WebCT