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

<table>
<thead>
<tr>
<th>quantity</th>
<th>formulation</th>
<th>Complex unit</th>
<th>For short</th>
</tr>
</thead>
<tbody>
<tr>
<td>velocity</td>
<td>dist/time</td>
<td>m/s</td>
<td>—</td>
</tr>
<tr>
<td>acceleration</td>
<td>velocity/time</td>
<td>m/s² = m/s/s = m/s per s</td>
<td>—</td>
</tr>
<tr>
<td>force</td>
<td>F=ma</td>
<td>kg m/s²</td>
<td>Newton (N)</td>
</tr>
<tr>
<td>work/energy</td>
<td>W=Fd</td>
<td>kg m²/s²</td>
<td>Joule (J = N·m)</td>
</tr>
<tr>
<td>power</td>
<td>energy/time</td>
<td>kg m²/s²</td>
<td>Watt (W = J/s)</td>
</tr>
<tr>
<td>frequency</td>
<td>cycles/second</td>
<td>1/s</td>
<td>Hertz (Hz)</td>
</tr>
<tr>
<td>pressure</td>
<td>force/area</td>
<td>kg/m²/s²</td>
<td>Pascals (Pa = N/m²)</td>
</tr>
</tbody>
</table>

Electrical Units

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

<table>
<thead>
<tr>
<th>quantity</th>
<th>formulation</th>
<th>units</th>
<th>for short</th>
</tr>
</thead>
<tbody>
<tr>
<td>charge</td>
<td>I</td>
<td>Coulombs</td>
<td>C</td>
</tr>
<tr>
<td>current</td>
<td>charge/time</td>
<td>C/s</td>
<td>Amps (A)</td>
</tr>
<tr>
<td>voltage</td>
<td>V = IR</td>
<td>V</td>
<td>Volts (V)</td>
</tr>
<tr>
<td>resistance</td>
<td>R = V/I</td>
<td>volts/amp</td>
<td>Ohms (Ω)</td>
</tr>
<tr>
<td>power</td>
<td>P = VI = FR = V²/R</td>
<td>volt-amps</td>
<td>Watts (W = J/s)</td>
</tr>
<tr>
<td>electric field</td>
<td>voltage/distance</td>
<td>V/m</td>
<td>—</td>
</tr>
</tbody>
</table>
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
- 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/s² (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

\[ \text{Force} = \text{mass} \times \text{acceleration} \]

- 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

\[ \text{Total Force} = \text{Force #1} + \text{Force #2} \]

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

- The real pairs have to involve the earth:
  - earth-box (grav)
  - box-floor (contact)
  - earth-satellite (grav)

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

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:
  \[ F_{\text{grav}} = \frac{GMm}{r^2} \]
  – 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.
  – Note that since \( F = ma \), we can say
  \[ a_{\text{grav}} = \frac{GM}{r^2} \]
  is the acceleration due to gravity

Gravity on earth’s surface

• The product, \( GM \), for earth, is \( 3.986 \times 10^{14} \) m\(^3\)/s\(^2\)
  – so \( a_{\text{grav}} \) 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 \( F = ma = (1 \text{kg}) \cdot (10 \text{m/s}^2) = 10\) 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)
  – 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