Build IT

Main concepts

Inertia

- An object's resistance to having its motion changed
- The more inertia an object has, the more difficult to change its motion
- Example: Consider two objects, one with small inertia (a ping pong ball) and one with larger inertia (a tennis ball).
    - If each is pushed with the same force, then the ping pong ball will have a greater change in its motion than the tennis ball. If you had both sitting still and blew on each the ping pong ball would accelerate (change its motion) much faster than the tennis ball.
    - In order to have both balls change their motion equally, you would have to apply more force (blow harder) on the tennis ball than on the ping pong ball.
- A good measure of inertia is mass.

Force

- A push or pull.
- Causes a change in motion (acceleration).
- Without a force, an object cannot change its motion and will simply either remain at rest or go in a straight line at a constant speed.
- Larger forces cause larger changes in motion.
- Multiple forces on an object add up to an overall force, which then determines the change in motion. When adding the forces, direction is considered.
- Example: Consider a small boat floating in the water.
    - If you do nothing, it will simply sit there. But if you push on it, then it will accelerate until you stop pushing.
    - When you let go, the boat continues moving forward, but starts to slow down. Why? After all, with no forces on it, it should keep moving at a constant speed. The reason is slows is that there is another force acting on it – drag from the water.

Newton's 3rd Law

- When an object is pushed, it will push BACK with an EQUAL force on whatever did the pushing.
- Often phrased like, "For every action, there is an equal and opposite reaction." (But be careful – it is often overlooked that the action and reaction are on different objects, never the same one.)
- Example: Consider a boat with a propeller floating in the water.
    - When the engine is turned on and the propeller turns, it pushes water away from the boat.
    - But then that causes the water to push back on the propeller with the same force, so the boat starts to move forward.
    - Notice that boat and water move away from each other with different speeds even though they push on each other with the same force. Why? Because they have different masses and thus inertias. The water has less inertia, so that same force makes it accelerate faster than the boat, which has more inertia.

Torque

- A twisting force.
- Caused by a force that doesn't pass through the CM of an object.
- The stronger the force, and the further away it is from the CM, the stronger the torque.
- Example: Consider a soda or water bottle with the cap screwed on tightly.
    - Try opening it by twisting the cap with your hands.
    - Now retighten it, and try the same thing, but this time, have a wrench clamped onto the cap. This should be much easier because your force is further away from the CM, causing a bigger torque.

Center of Mass and Rotation

- The point in space that represents where the average of the mass of an object is located.
- Forces on the object that act on a line that passes through the center of mass (CM) simply cause the object to accelerate, but not rotate.
- Forces on the object that act on a line that doesn't pass through the center of mass cause the object to rotate.
- The strength of the rotation force is called torque.
- Example: Consider a boat with a propeller floating in the water.
    - If everything in the boat is laid out in the center of the boat, then when the engine is turned on, the boat will move forward. The reason is that the push from the propeller passes through the center of mass of the boat, so it goes straight.
    - If everything is piled up on the right side, then the boat will turn to the right. This is because the CM has shifted to the right, and the push from the propeller no longer passes through it. So a rotation begins.

Buoyancy

- Whenever an object is put in water (or any liquid), it will experience a force upward from the water. This is called the buoyant force.
- The more water an object displaces (moves out of the way to make room for it), the larger the buoyant force.
- The object is also being pulled down by its weight.
- If the object's weight is smaller than the buoyant force, then the object is positively buoyant, and will rise to the surface.
- If the object's weight is larger than the buoyant force, then the object is negatively buoyant, and will sink to the bottom.
- If the object's weight and the buoyant force are exactly equal, then the object is neutrally buoyant, and will remain still, neither rising nor sinking, no matter where in the water it is placed.
- Example: Consider a small boat floating in the water.
    - Attach some pool noodle foam to the top of the boat so that it floats. Then push it down under the water and it will rise back up. At this point, the buoyant force of the water is stronger than the weight of the boat. The boat is positively buoyant.
    - Put one or two heavy bricks in the boat until it sinks. Now the weight is greater than the buoyant force. The boat is negatively buoyant.
    - Finally, take the heavy bricks out of the boat and gradually add coins or other weights until the boat neither sinks nor floats when placed fully under the water. (You may not reach this point exactly, but you can get very close, so that the boat takes a long time to sink or rise.) Now the boat is neutrally buoyant, and the weight and buoyant force are equal to each other.
- Extra: Where does the buoyant force come from?
    - As you go deeper into water, the pressure increases, due to the weight of all the water above you.
    - This pressure pushes in all directions, due to water being a liquid. (Imagine filling a balloon with water, tying it closed, putting it on a flat table, and then pushing down on it. Even though you exert a downward pressure, the balloon will bulge out at the sides. In fact, if you take a piece of tape, put it over a spot on the balloon, and then piece the balloon with a needle at that point, water will flow out in the direction of the hole. This will happen no matter where you puncture the balloon, showing that the pressure is exerted in all directions.)
    - When an object is placed under the water, the pressure from the water on the bottom of the object is stronger than the pressure on the top, causing a net push upward. That is the buoyant force.

Stability

- When an object is under the water, there are two forces on it – gravity and the buoyant force.
- Gravity pulls down on the object, trying to make its center of mass (or center of gravity) go as low as possible.
- The buoyant force, however, pushes on the center of buoyancy, which tends to be very close to the least dense parts of the object. The buoyant force tries to get the center of buoyancy to go as high as possible.
- So, if the center of buoyancy is lower than the center of mass, then the opposing forces of buoyancy and gravity will try to make the boat twist until the center of mass is directly below the center of buoyancy.
- Example: Consider a small boat floating in the water.
    - Attach some pool noodle foam to the bottom of the boat and a heavy brick to the top. The center of buoyancy will be near the foam, and the center of mass will be near the brick. The boat will very badly want to flip over, since gravity pulls down strongly on the brick down and the buoyant force pushes up strongly on the foam.
    - Put both the foam and the heavy brick in the middle of the boat. If you place it just right, the boat will be easy to flip one way or the other. There won't be much preference, if any.
    - Finally, put the foam on the top and the heavy brick on the bottom. Now the boat should be very stable, and if tipped will correct itself.

Gears

- A type of simple machine.
- Example: Consider a simple LEGO two-gear system with a large and small gear.
    - The large gear has 40 teeth, and the small gear has 8 teeth.
    - When the first gear has turned through one full rotation, its 40 teeth have moved the same number of teeth on the small gear. But to get through that number of teeth, that means that the small gear must have turned 5 times. In other words, it's going faster.
    - The two gears will spin in opposite directions.
    - The twisting force (torque) of the second gear will be weaker than the first. Once way to understand this is to imagine the force that was applied to the first gear, which was applied for a full rotation. But since the second gear goes through more than one rotation, the effort you put in is spread out, and so is weaker. So since the small gear rotates 5 times for each rotation of the large gear, the twisting force of the small gear will be 5 times smaller.