

MOMENTUM

- Inertia (mass) in motion (velocity) is **momentum**
 - Momentum = mass \times velocity = mv
 - It is a property of moving things.
- Can have large momentum if either mass or velocity is large.
 - A heavy truck is harder to stop than a light car at the same speed.
 - A car is harder to stop when it is moving fast than when it is moving slow.
- Why does a supertanker need to cut its engines 25 km from port?
 - It has huge momentum due to its huge mass, and so it takes a long time for water resistance to slow it down.

IMPULSE

- Impulse is a change in momentum, usually due to a change in the velocity, i.e. acceleration, which is caused by a force.
- Force and the time that the force acts determine the impulse.
 - Greater force produces a greater change in momentum.
 - Force applied over a long time produces a greater change in momentum than the same force applied briefly.
 - Impulse = Force \times time interval = Ft
- Impulse changes momentum
 - $a = F/m$ $a = \Delta v/t$
 $F/m = \Delta v/t$
 $Ft = \Delta(mv)$
- Increasing momentum: greater force or longer time
 - Longer barrel cannon for maximum range
- Decrease momentum over a long time: obtain small forces
 - DEMO: jump off of the table
 - Driving a runaway car through a haystack instead of a wall
 - Catching a ball with your extended hand pulled backward
- Decrease momentum over a short time: obtain large forces
 - Karate chop
 - DEMO: egg toss into a pan vs. into a sheet
- CHECK QUESTION: why are stages and roller rinks made of wood?
- Are impulses greater or lesser if an object bounces off of something else?
 - Greater: because the momentum change when stopping an object and throwing it back is greater than the momentum change when simply stopping an object.

CONSERVATION OF MOMENTUM

- To change an object's (or system's) momentum, an impulse must be applied from something external to the object or system.
 - Push the dashboard from inside a car: internal forces – no momentum change for the car.
 - Push car from outside: force external to car, momentum change possible.

- If there are no external forces on a system, momentum of the system doesn't change: *Conservation of Momentum*.
 - CHECK QUESTION: Rifle and bullet system: do the speeding bullet and recoiling rifle have the same momentum after the bullet is fired?
 - Equal magnitude: forces equal (Newton's 3rd Law), time is the same since exploding gunpowder acts on both for the same time.
 - Opposite direction: vector quantity, the rifle's and the bullet's momenta must add to zero since the momentum of the system was zero before it was fired.
 - DEMO: air track, magnets

COLLISIONS

- Momentum is conserved in collisions because the forces acting are internal to the system of colliding objects.
 - Elastic collision: rebound with no deformation or heat generated, e.g. billiard balls.
 - DEMO: air track, collisions
 - Inelastic collision: deformation and/or heat generation, e.g. in a perfectly inelastic collision, colliding objects stick together.
 - DEMO: air track, collisions
 - FIG: 6.14, calculate
 - FIG: 6.17, calculate

WORK

- Work = force \times distance, $W = Fd$
 - Amount of work done by a force is the product of the applied force and the distance the object moves in the direction of the force.
 - Unit of work is the joule: $1 \text{ J} = 1 \text{ N}\cdot\text{m}$
- Which is more work: 50 N sack lifted 2 m or 25 N sack lifted 4 m?
- Does gravity do work on a car rolling down a hill? Rolling on a level road?
- Crate pulled across the floor at constant velocity
 - Is work done by the pull of the rope (is it canceled by the pull of the crate on the rope?)?
 - Is work done by friction?
- What work is done by a weightlifter while lifting? While holding?

POWER

- Power = work/time interval, rate at which work is done.
 - Unit of work is the watt: $1 \text{ W} = 1 \text{ J/s}$
- Which takes more power: 50 N sack lifted 2 m in 1 s or 25 N sack lifted 4 m in 2 s?
- 1 L of fuel can only do a certain amount of work, but can produce almost any amount of power depending on how fast it is burned.
 - Run a lawn mower for half an hour at low power.
 - Run a jet engine for half a second at 3600 times the power.

MECHANICAL ENERGY

- Work done on an object gives that object the ability to do work.
 - The thing that work gives an object is energy.
- Mechanical energy includes energy due to the position of an object (potential energy) and energy due to an object's motion (kinetic energy).

POTENTIAL ENERGY

- Potential energy is stored energy due to an object's position.
- Must do work on an object to give it potential energy, then that object is capable of doing work.
- Gravitational potential energy
 - Amount of gravitational potential energy equals the amount of work done lifting it.
 - $W = Fd = \text{weight} \times \text{height}$
 - $PE = W = mgh$
 - Height is relative to some reference level (ground, floor, etc.). Grav. PE is always relative to some arbitrary point you choose.
- Other potential energy: drawn bow and arrow, stretched rubber band, battery (chemical PE)
- CHECK QUESTIONS: page 114

KINETIC ENERGY

- Kinetic energy is the energy of motion.
- Must do work on an object to change its motion. An object in motion is capable of doing work.
- Kinetic energy = $\frac{1}{2} \text{ mass} \times \text{speed}^2$, $KE = \frac{1}{2} mv^2$
- How much KE does a 1 kg book tossed at 2 m/s have? 2 J
 - What if I double the mass of the book? Double the speed?

WORK ENERGY THEOREM

- Work equals change in kinetic energy.
 - $W = \Delta KE$
- What takes more work to stop, a light truck or a heavy truck at the same speed?
- What takes more work to stop, a light truck or a heavy truck with the same momentum?
- Why do long-range cannons (or rifles) have long barrels?
 - $W = Fd$, longer distance for the force to act (i.e. longer barrel) produces more work on the projectile. $W = \Delta KE$, more work, more kinetic energy, more speed for the projectile. (Very similar to the same question answered with Impulse = force \times time = Δmv)
- Skidding distance
 - When you slam on the brakes and skid, the road does work on the car to stop it through the force of friction.
 - Friction doesn't depend on speed, but on the distance needed to stop.
 - A car at 50 km/h skids 15 m when the brakes are slammed, how far will the car skid if the brakes lock at 150 km/h?

CONSERVATION OF ENERGY

- What is important about energy is how it transforms from one form into another and how it transfers from one place to another. The greatest generalization of the behavior of energy is the law of conservation of energy.
 - DEMO; sledgehammer cinder blocks stacked on me while lying on a bed of nails.
- **Conservation of Energy:** energy cannot be created or destroyed; it may be transformed from one form into another, but the total amount of energy never changes.
- DEMO: pendulum
 - At what point is KE a maximum?
 - At what point is PE a maximum?
 - When KE is half its maximum, how much PE does it have?
 - Energy is constantly being transformed back and forth between potential and kinetic energy.
- Examples
 - Ball dropped vs rolling down an incline an equal height.
 - What is the speed at the bottom?
 - Pile driver – where does the initial PE go?
 - PE at top = KE at bottom = Work done on piling + heat generated
 - Bow and arrow
 - Solar energy
 - Atoms fuse together and give off radiant energy
 - Plants use the light to create tissue
 - Becomes coal
 - Converted into heat/electrical energy
 - Eaten by animals
 - Become oil
 - Converted into heat/electrical energy
 - Evaporates water (lifts it into atmosphere)
 - Rains down
 - Trapped behind dam, converted to electricity
 - all of it eventually degrades into heat released into the environment

MACHINES

- A machine is a device that multiplies the force or the distance of work, or simply changes the direction of the force.
 - Cannot multiply energy or work – conservation of energy!
- An ideal machine loses no work (energy) to friction, heating, etc.
 - Work Input = Work Output
 - $(Fd)_{\text{input}} = (Fd)_{\text{output}}$
- Lever: you do work on one end, the other end does work on the load. Changes the direction of the force.

- Put the fulcrum near the load to multiply the force in order to lift something that is too heavy for you to lift yourself.
 - DEMO: $(F\mathbf{d})_{\text{input}} = (F\mathbf{d})_{\text{output}}$
- Put the fulcrum near you to multiply the distance in order to lift something higher (generally not very useful this way).
 - DEMO: $(F\mathbf{d})_{\text{input}} = (F\mathbf{d})_{\text{output}}$
- Efficiency: no machine is ideal or perfect. All machines “waste” some of the input work due to heating (friction, etc.).
 - Efficiency = (useful energy output)/(total energy input)
 - Lever: can be relatively high efficiency (~98% for light load, 60% for car jack).

CONSERVATION OF ENERGY VS CONSERVATION OF MOMENTUM

- DEMO hanging balls
 - Why when I drop two balls, two balls pop out of the other side with the same speed as the released balls on impact due to conservation of momentum.
 - If only one ball popped out of the other side at twice the speed, momentum would still be conserved. Why does this never happen?

CIRCULAR MOTION

- *Linear speed, v* : the distance in meters moved per unit time. This is what we usually just call speed. Points on the outside of a rotating object have greater linear speed than those inside closer to the axis. The speed of something moving along a circular path can also be called *tangential speed*, since the direction is tangent to the circle.
- *Rotational speed (angular speed), ω* : the number of rotations per unit time. All points on a rigid rotating object have the same rate of rotation. Can be measured in revolutions per minute (RPM), degrees per second or radians per second (there are 360 degrees or 2π radians (~ 6.3) in one revolution).
 - The unit radian/sec is the most common for rotational speed.
- Tangential speed is directly proportional to rotational speed and directly proportional to radial distance from the axis.
 - $v = r\omega$
 - Only valid for a rigid rotating system. Does not work for a non-rigid system like the orbiting planets or horses running around a track.
- DEMO: spinning wheel

ROTATIONAL INERTIA

- Rotational inertia is the property of an object to resist changes in rotational motion.
 - An object rotating about an axis tends to remain rotating about the same axis at the same speed unless interfered with by some external influence (an influence called a torque).
- Rotational inertia, like regular inertia, depends on the mass of the object. But it also depends on the distribution of the mass relative to the axis of rotation.
 - The more mass is concentrated far from the axis, the greater the rotational inertia.
- DEMO: three rotational inertia values for a pencil
- DEMO: tightrope walking with a pole
- DEMO: aluminum rods with different rotational inertias
- DEMO: balancing a pole with a large mass on one end
- DEMO: meter stick drop with and without added mass
- DEMO: rolling ring, disk, sphere
- FIG: 8.15

TORQUE

- A force causes a change in linear motion.
- A torque causes a change in rotational motion.
 - $T = \text{Force} \times \text{Lever Arm}$
 - Lever arm is the shortest distance between the line of applied force and the rotational axis (perpendicular distance from the line of applied force to the axis).

- Example: wrench turning a bolt
- DEMO: pencil pushing
- DEMO: meter stick with dangling weight – torque feeler
- DEMO: race out of the door, pushing on different locations of the door
- Mechanical equilibrium
 - Need $\Sigma F = 0$
 - Also need $\Sigma T = 0$, where we take clockwise rotation as positive and counter-clockwise rotation as negative (or vice-versa).
 - Calculation: see-saw

CENTER OF MASS/GRAVITY

- Center of mass is the average position of all the mass in an object.
- Center of gravity is the average position of all the weight distribution of an object.
 - Same as CoM unless gravity varies from one part of the object to another, i.e. a very tall skyscraper.
- Entire weight can be thought of as acting at the CoG.
 - DEMO: meter stick balancing
- Find the CoG by suspending the object and dropping a straight line down. CoG has to lie somewhere along that line. Suspend the object from another point and drop a line. Wherever the second line crosses the first is the CoG.
 - DEMO: L-shaped CoG (where no mass exists!)
 - DEMO: Mississippi CoG
- CoG is higher (~1-2%) for men than women because men have more upper body muscle mass.
 - Like a baseball bat
 - CoG is near the belly button
 - No accident – fetus rotates around the CoG, umbilical cord won't get tangled up.

STABILITY

- DEMO: touching your toes freestanding vs. backed against a wall
- If a line dropped straight down from the CoG falls inside the base of an object, then the object is in stable equilibrium.
 - If the line falls outside the base, the object is unstable and will tip over.
 - Wide bases with low CoG are most stable.
 - FIG: 8.36
 - This is why SUV's are more unstable than cars or pickups.
- DEMO: L-shaped piece tips over
- DEMO: stand up from seated position without leaning forward or putting feet under chair.
- Pregnant woman's back pains as pregnancy progresses
 - Relieved by skis or a load on a pole (backpack)

CENTRIPETAL FORCE

- For any object moving along a curved path, there must be a real force causing the curved motion.
- Any force directed toward a fixed center is called a *centripetal force*.
- Identify the centripetal force involved with
 - A ball twirled on a string
 - A car rounding a corner
 - The moon revolving around the Earth
 - A washing machine
- Centripetal force is not a force in its own right, but the name we give to any real force that pulls an object in a curved path.
- DEMO: swinging a bucket of water
 - Why doesn't the water fall at the top of the path?
 - What provides the centripetal force?

CENTRIFUGAL FORCE

- Sometimes we seem to experience an outward-directed force when undergoing circular motion. This apparent outward-directed force is called a *centrifugal force*.
 - It is not a real force, but only an apparent one due to the fact that we are rotating. There is no thing that is exerting an outward force on us, and that we can exert a force back on to produce an action-reaction pair. Therefore centrifugal force is called a fictitious force.
- Example: we feel a pitch to the outside when we are riding in a car that turns a corner. What we actually feel is acceleration to the inside, not a force pushing us outside.

ANGULAR MOMENTUM

- All moving objects have momentum, or inertia of motion.
 - Momentum = mass \times velocity = mv

- All rotating objects have angular momentum, or inertia of rotation.
 - Angular momentum = rotational inertia \times angular velocity = $I\omega$
- Ball on a string (or planet orbiting the sun)
 - Momentum = mv
 - $I = mr^2$ (page 138), $\omega = v/r$ (page 134, footnote)
 - Angular momentum = $I\omega = mvr$
- Rotational version of Newton's 1st Law: an object or system of objects will maintain its angular momentum unless acted on by an unbalanced external torque.

CONSERVATION OF ANGULAR MOMENTUM

- If no net torque acts on a system, angular momentum is conserved.
 - Just like if no net force acts on a system, linear momentum is conserved.
 - Therefore the product of rotational inertia and angular velocity stays the same:
 - $(I\omega)_{\text{initial}} = (I\omega)_{\text{final}}$
- DEMO: standing on turntable with weights
 - $I\omega = I\Omega$
 - How does the length of a day change if
 - Soil is washed down the Mississippi River into the Gulf of Mexico
 - More skyscrapers are built
 - Leaves fall in the autumn