Announcements

- Help room hours (1248 BPS)
  - Ian La Valley(TA)
  - Mon 4-6 PM (except not Monday Sept 17)
  - Tues 12-3 PM
  - Wed 6-9 PM
  - Fri 10 AM-noon
- First exam Tuesday Oct. 2 10:20 AM this room
  - you may bring 1 sheet of hand-written notes; no xeroxing; bring picture ID
- Final Exam Tuesday Dec 11 7:45-9:45 AM

Temperature

- The quantity that indicates how warm or cold an object is compared to some standard is called temperature
- We use a device graduated in a scale (degrees) to measure the temperature
  - a thermometer works by means of expansion or contraction of a liquid, usually mercury or colored alcohol
- The most common temperature scale in the world is the Celcius (also called Centrigrade) scale named after Anders Celcius
  - 100 degrees between the freezing point of water and its boiling point
- But in the United States, the Farenheit scale is more common, named after the German physicist Farenheit
  - in this scale, water freezes at 32 degrees and boils at 212 degrees
  - 0^{o} is the temperature of the coldest salt water solution
  - in official use only in the US and in Belize

The Quest for Absolute Zero (10’00’’ – 18’30”)

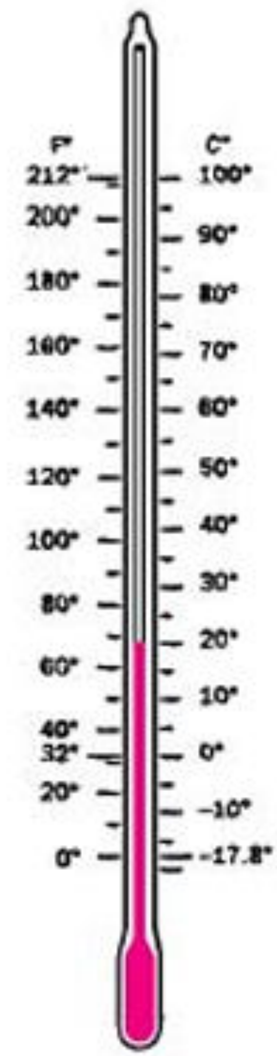
Conversions

- Temperature
  (C – Celcius, F – Farenheit)

$$T_C = \tfrac{5}{9}T_F - 32 \quad \text{and} \quad \rightarrow T_C + 32 = \tfrac{5}{9}T_F$$

$$\tfrac{9}{5}\left(T_C + 32\right) = T_F$$

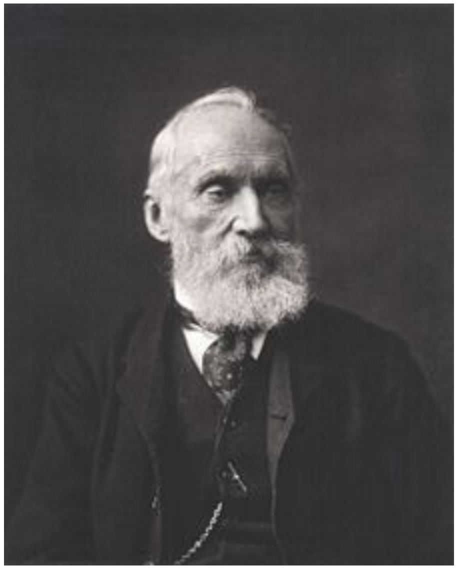
- The two are equal at -40^{o}, cold no matter what scale you use to quote it
- You should know how to convert from one scale to the other



Absolute zero

- In the 19th century, physicists found something amazing
- Suppose you start with a gas at 0^o C
- The volume decreases by a fraction 1/273 for every degree decrease in temperature
- This implied that if a gas were cooled to -273^o C, it would decrease to zero volume
  - of course, by this point the gas would have turned into a liquid, but it brings up the idea that, while there is no upper limit to temperature, there is a lower limit
- At -273.15^o C, molecules have lost all available kinetic energy
  - It's impossible to remove any more heat

- This temperature is called absolute zero
- The Kelvin temperature scale uses absolute zero as the zero of the temperature scale (but the degrees are the same size as for the Celcius scale)
- The temperature scale is named after Lord Kelvin, another illustrious Scottish physicist



But originally By William Thomson

The Quest for Absolute Zero
(57'40'' – 1h12'48")

Units for heat

- Heat is measured in units of energy, or Joules
- It takes 4.18 Joules to raise 1 gram of water by 1 degree C
  - this is an experiment that either you have performed, or will perform, in ISP209L
- The energy ratings of food are determined from the energy released when they are burned
  - a person's metabolism is really burning, at a slow rate
- The heat unit for food is the kilocalorie (=1000 calories)
  - able to raise 1 kg of water by 1 degree C
- To avoid confusion, the food unit is called a <u>C</u>alorie (cap C)

Calories and heat

- Suppose you eat a peanut
- That's 10 Calories and 10,000 calories (or 41800 J)
- Suppose you eat a total of 2000 Calories a day
- That's 2E6 calories or 8.36E6 J
- There are 24 hours X 60 min/hour X 60 s/min = 86,400 s/day
- Power = Energy/Time =(8.36XE6 J)/(8.64E4 s) = 96 W
- So if all of your energy intake ends up as heat (not a bad assumption), then your body is radiating as much heat as a 100 W light bulb

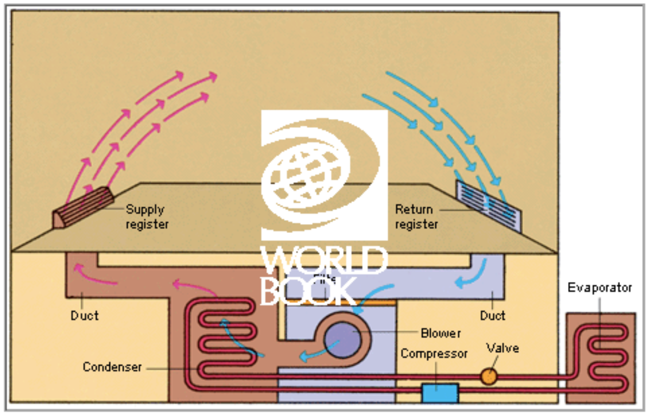
Suppose there are 100 of you crowded in a small room with no air conditioning. That's 10kW of heat being produced.

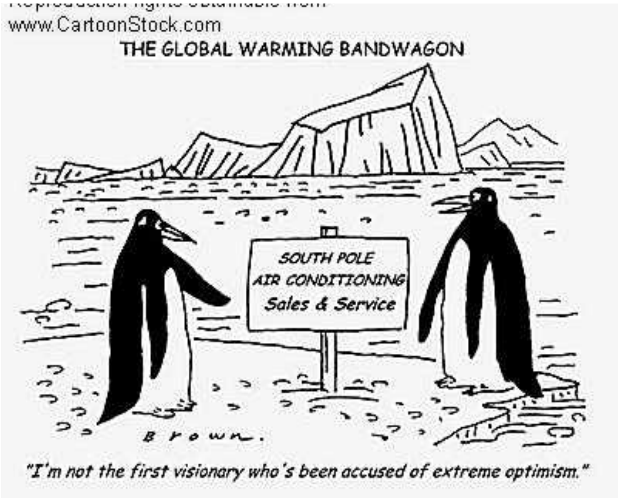
Laws of thermodynamics

- First law: whenever heat is added to a system, it transforms to an equal amount of some other form of energy
  - heat added = increase in internal energy + external work done by system
- Suppose you put an air-filled, rigid air-tight can on a hot stove (not recommended)
- Since the can has a fixed volume, no work can be done on the can by the air
- All of the heat applied increases the internal energy of the air, so the temperature rises
- If the can can expand, some of the added heat goes into doing work, moving the walls of the can
  - so the increase in temperature of the enclosed air is less, since the total energy is conserved

Second law

- Heat never spontaneously flows from a cold substance to a hot substance
- Heat can be made to flow the other way only when work is done on the system, as for example with a heat pump or an air conditioner





Third law

- No system can reach absolute zero
- To do so would require that there be no energy present anywhere in the universe
  - but in the laboratory, we have been able to go down to temperatures of less than a millionth of a (degree) Kelvin above absolute zero

superconducting magnets such as at the LHC and the NSCL operate at a few degrees K

Re-statement of 3 laws of thermodynamics

1. You can't win
   - you can't get more energy out of a system than was put into it
2. You can't even break even
   - you can't get as much useful energy out as the amount put in
3. You can't get out of the game
   - entropy in the universe is always increasing

entropy

$$\Delta S = \frac{\Delta Q}{T}$$

the increase in entropy is equal to the amount of heat added to the system divided by the temperature at which it was added

- In natural processes, *high-quality* energy tends to transform into *lower-quality* energy
  - order tends to disorder
  - entropy, a measure of disorder, always increases for a closed system
  - time's arrow always points from order to disorder
- What about the Earth? Entropy can be seen to decrease
  - not a closed system
  - energy input from the Sun
  - total entropy in the solar system increases

Entropy

- We can also write the entropy of a system as $S=k_B \ln(W)$, where k_B is the Boltzmann constant and W is the number of possible states for a system, and ln is the natural logarithm on your calculator
- The larger the number of possible states, the larger the entropy
- The universe began with very low entropy (very small volume, fewer possible states)
- The entropy of the universe has been increasing since then
  - it's a closed system
- Consider for example a set of 12 coins
- The number of possible states for the system is the number of ways you can have n heads and 12-n tails
- It is very unlikely that you will roll the 12 dice and find they all have sixes
- Another experiment you have carried out in ISP209L

Heat death of the universe

- As stars form and burn out, the energy in the universe is conserved, but it becomes more uniformly distributed
- If the energy in the universe is uniformly distributed, then all parts of the universe are at the same temperature, and no useful work can be done (and no life can exist)
- The universe is in a state of maximum entropy and encounters *heat death*
- It will take about 10^{100} years for the last black hole to decay away
  - but luckily, by then the universe may be ripped apart by expansion due to dark energy
  - which we will discuss in later lectures.

Lightning review for first exam

- Exam 1 will have 40 multiple choice questions based on the material covered in lectures
- No material will be from the text, if not covered in the lectures
- Some of the questions will involve calculators
  - but no cell-phones can be visible
- You may bring one sheet of paper with notes for the exam
- Bring a picture ID

Basics

- Understand scientific notation
  - $0.003 = 3 \times 10^{-3} = 3\text{E}{-3}$ (on calculators)
  - understand km, cm, mm, μ m, nm
- Know the SI units for the quantities we have been working with
  - position – m (meters)
  - Time – s (seconds)
  - speed – m/s
  - acceleration – m/s^2 (or N/kg)
  - force – N (newtons)
  - mass – kg (kilograms)
- Understand the differences between science and pseudoscience

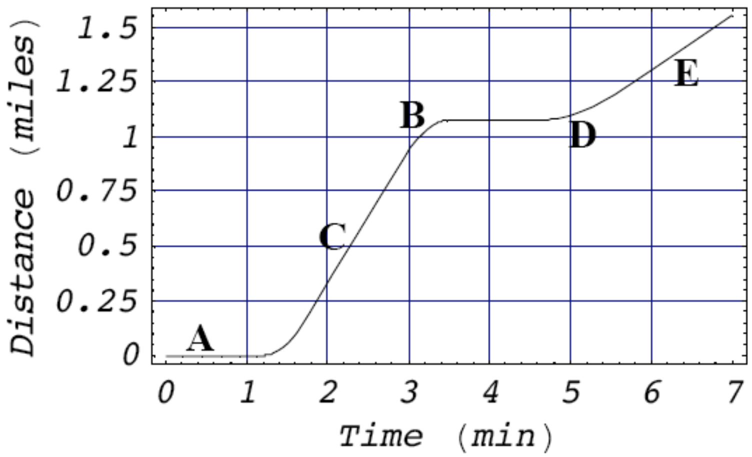
Scalars, vectors and tensors

- A scalar is a quantity that is just a number
- A vector quantity has both a magnitude and a direction
  - know how to add vectors
- A tensor is a generalization of the above two quantities in multiple dimension
  - rank 0 is a scalar
  - rank 1 is a vector
  - rank 2, or higher is a more complex quantity that has two directions and two magnitudes (curvature of space-time)

Motion

- Know definition for these vectors
  - displacement (position)
    - distance=magnitude of displacement
  - velocity
    - speed=magnitude of the velocity
  - acceleration
- Be able to use a graph to determine position, velocity and acceleration at any point
- Be able to use kinematic equations of motion
  - for motion in x direction
  - for vertical motion (with effects of gravity)
  - projectile motion

* Where is the acceleration negative?

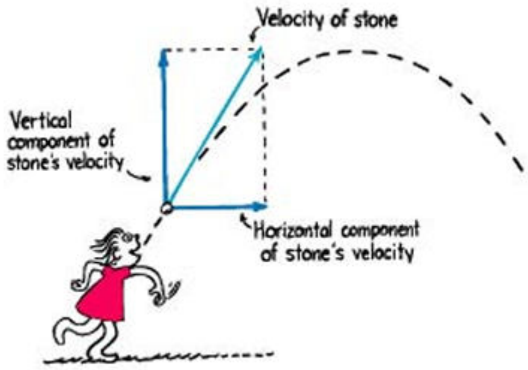


x direction ⟶ + is to the right, - is to the left

* Is there acceleration at A? At D?
* Are they the same?

Projectile Motion

- But let's start simple
- I throw the ball horizontally with a speed of $v_o^x = 20$ m/s
- How long before it hits the ground?
- How far has it travelled?



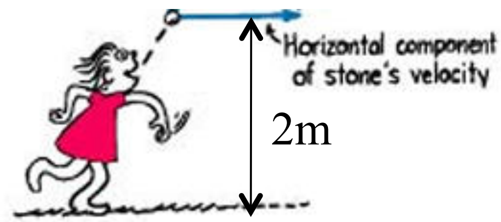
Projectile motion equations

$$x = x_0 + v_0^x t$$

$$y = y_0 + v_0^y t - \frac{1}{2} g t^2$$

Projectile Motion

- Assume that I release it 2 m from the ground
- $y_o = 2$ m, $v_o^y = 0$ m/s



Get the time t, to hit ground

$$y = y_o - \frac{1}{2} g t^2$$

$$0 = 2\,\mathrm{m} - \frac{1}{2}(9.83\,\mathrm{m/s^2}) t^2$$

$$t^2 = \frac{4\,\mathrm{m}}{9.83\,\mathrm{m/s^2}} = 0.407\,\mathrm{s^2}$$

$$t = 0.64\,\mathrm{s}$$

Position x, when hitting the ground

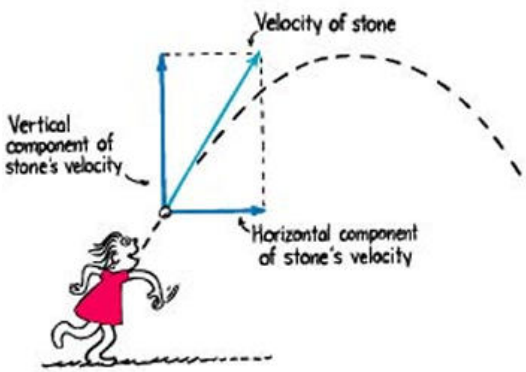
$$x = x_o + (20\,\mathrm{m/s^2})(0.64\,\mathrm{s}) = x_o + 12.8\,\mathrm{m}$$

$$x = x_0 + v_0^x t$$

$$y = y_0 + v_0^y t - \frac{1}{2} g t^2$$

Projectile Motion

- Now, suppose I throw it at 20 m/s and at an angle of 45°
- Start again with vertical motion to get the time.



$$0 = 2\,\mathrm{m} + (20\,\mathrm{m/s})\sin 45^{o}\, t - \frac{1}{2}(9.83\,\mathrm{m/s^2})t^2$$

$$0 = 2\,\mathrm{m} + (20\,\mathrm{m/s})(0.707)t - (4.915\,\mathrm{m/s^2})t^2$$

$$4.915t^2 - 14.14t - 2 = 0 \text{ (quadratic equation)}$$

$$t = 3.01\,\mathrm{s}$$

$$x = x_0 + v_0^x t$$

$$y = y_0 + v_0^y t - \frac{1}{2} g t^2$$

- Then horizontal motion

$$x = x_0 + (20\,\mathrm{m/s})(\cos 45^\circ)t$$

$$x = x_0 + (20\,\mathrm{m/s})(0.707)(3.01\,\mathrm{s}) = x_0 + 42.6\,\mathrm{m}$$

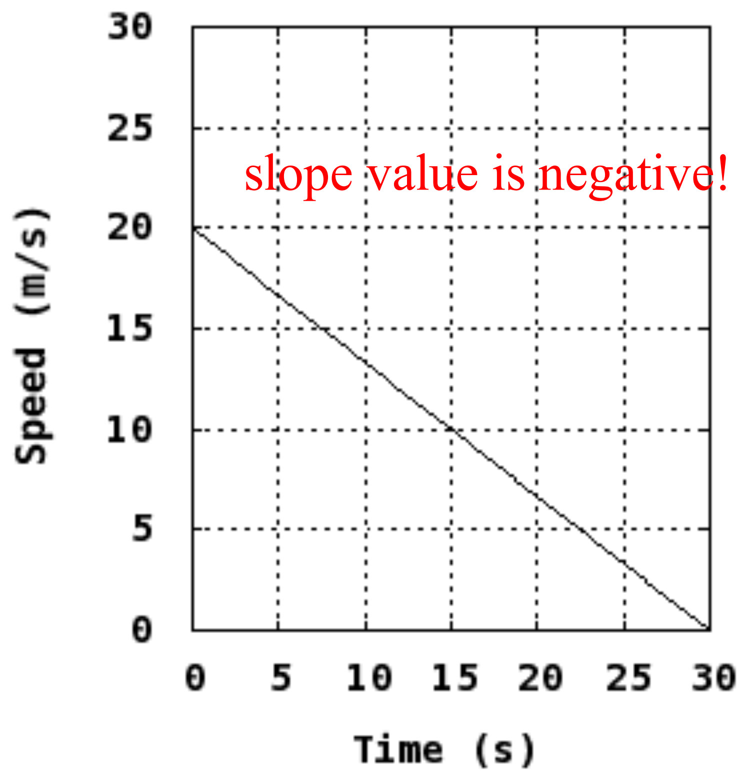
Force, mass and laws of motion

- A force is a push or pull
- The mass of an object measures the amount of resistance to a change in motion or its inertia
- Know the difference between Galileo's understanding of motion and that of Aristotle
- Know Newton's 3 laws
  1. If the sum of forces acting on an object is zero it does not accelerate. $\vec{F}$
  2. $\vec{F} = m\vec{a}$
  3. For each force acting on one object, an equal magnitude and opposite direction force acts on another object.
- Know implications of Newton's 3 laws, for example, the Moon pulls as hard on the Earth as the Earth pulls on the Moon (3rd law)
- Know how to carry out simple problems involving Newton's 3 laws
- Impulse = Force X Time
- Force is the rate of change of momentum. Given a graph of momentum vs time, you should be able to calculate the force .

Force and acceleration

- We had this problem in the homework: A car of mass 2180 kg slows down with a constant acceleration as the brakes are applied.
- What force is acting to slow the car down?
- Note: the plot of speed vs. time has a uniform slope = acceleration

$$a = \frac{\Delta v}{\Delta t} = \frac{0\,\mathrm{m/s} - 20\,\mathrm{m/s}}{30\,\mathrm{s}} = -0.67\,\mathrm{m/s^2}$$



- If there's an acceleration then there must be a force causing that acceleration, and the force

$$F = ma = (2180\,\mathrm{kg})(-0.67\,\mathrm{m/s}) = -1453\,\mathrm{N}$$

- If only force magnitude is required the answer is $|F| = m|a| = (2180\,\mathrm{kg})(0.67\,\mathrm{m/s}) = 1453\,\mathrm{N}$

Kepler’s 3 laws and Newton’s law of universal gravitation

- Tycho Brahe’s detailed measurements allowed Johannes Kepler to develop his 3 laws of planetary motion
- Know Kepler’s 3 laws and how Newton’s law of gravity explains them
  - elliptical orbits - mathematical result of Newton’s laws
  - planets move faster when they are closer to the Sun, where the gravitation force between them is greater
  - square of the period is proportional to the cube of the semi-major axis (largest distance between planet and Sun); this is where the distance is largest and the gravitational force is weakest.

Newton's law of gravity

- Know Newton's law of gravity and how to use it to calculate the force of gravity between two masses
- Know why an astronaut in orbit appears weightless
- Why do all objects fall (accelerate) in a vacuum at the same rate?
  - Because the inertial mass (the mass in $F = ma$) is the same as the gravitational mass, in the law of gravity, $F = GMm/r^2$.

Weight

- Let's consider the force the Earth exerts on you, i.e., your weight.
- Suppose your mass is 60 kg
- Values in Gravitational force law

$$m_1 = m_{\text{Earth}} = 6 \times 10^{24}\,\text{kg}$$
$$m_2 = m_{\text{You}} = 60\,\text{kg}$$
$$d = R_{\text{Earth}} = 6.37 \times 10^{6}\,\text{m}$$

- Gravitational force:

$$F = G\frac{m_1 m_2}{d^2}$$

$$F = \left(6.67 \times 10^{-11}\,\text{Nm}^2/\text{kg}^2\right)\frac{(6 \times 10^{24}\,\text{kg})(60\,\text{kg})}{(6.37 \times 10^{6}\,\text{m})^2}$$

$$F = 591\,\text{N}$$

If you were twice as far away from the center of the Earth, your mass would be the same, but your weight would be

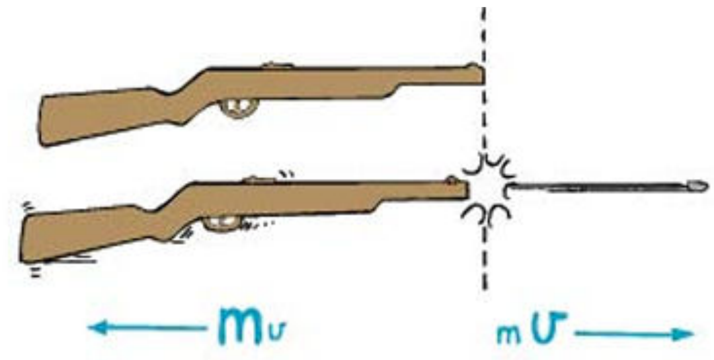
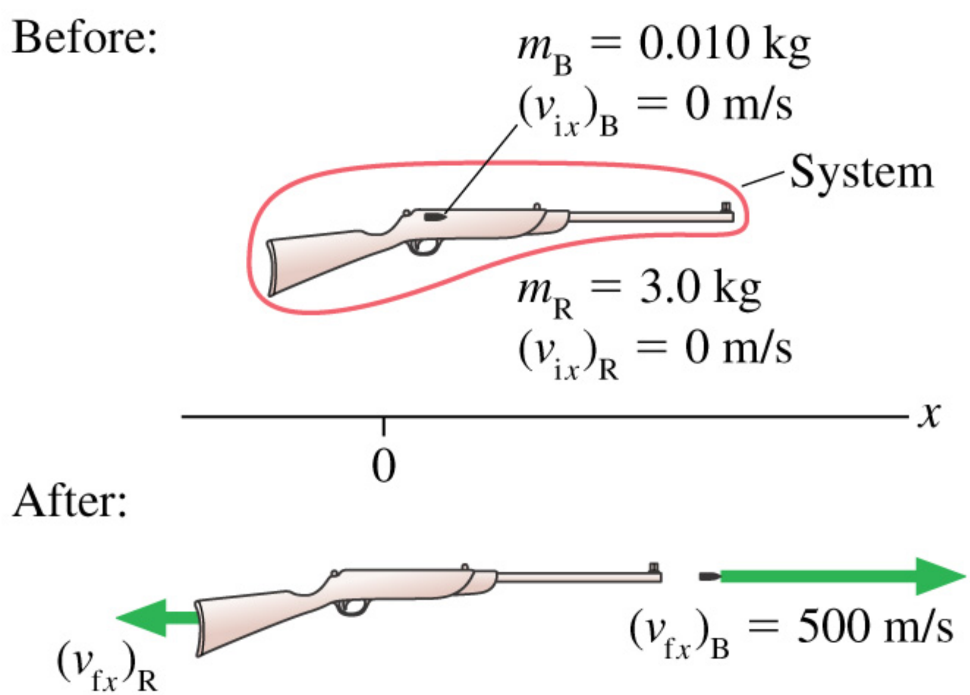
F = (591 N)/4=148 N

Conservation laws

- Understand conservation of energy and conservation of momentum
- Be able to understand conversions of kinetic energy, ($KE=1/2\ mv^2$) into potential energy (mgh for gravity) and vise-versa.
- Work = Force X Distance (units of Joules)
- Work = change in *KE* (or = change in *PE*)
- Power = Work/Time
- Simple machines – lever, pulley
- Efficiency = Output work/Input energy

Conservation of momentum

- Let's go back to the rifle firing a bullet
- Only an impulse external to the system can change the total momentum of a system
- So the total momentum of the rifle + bullet system is conserved
- So the momentum of the bullet equals the recoil momentum of the rifle
  - Mv = mV
- Since M >> m, V >> v
- But P_{rifle}=P_{bullet}

Conservation of energy

- So the circus performer has a PE of 10,000 J (and a mass of 50 kg)
- How high is the performer?

$$PE = mgh$$

$$h = \frac{PE}{mg} = \frac{10{,}000\,\mathrm{J}}{(50\,\mathrm{kg})(9.8\,\mathrm{m/s^2})} = 20.4\ (\text{units})$$

- What are the units?
  - J is a unit of energy
  - So 1 J = 1 kg•m^2/s^2 (like KE=1/2 mv^2)
  - so *h* = 20.4 m
- What is the speed of the performer when hitting the bucket?

$$KE = \frac{1}{2}mv^2 = \Delta PE = 10000\,\mathrm{J}$$

$$v^2 = \frac{(2)(10000\,\mathrm{J})}{50\,\mathrm{kg}} = 400\,\mathrm{J/kg}$$

$$v = 20\,\mathrm{m/s}$$