THE LAWS OF THERMODYNAMICS

PES 1000 – PHYSICS IN EVERYDAY LIFE

THE LAWS OF THERMODYNAMICS

- There are three fundamental laws that describe the relationships between heat, temperature, internal energy, and entropy.
- Two laws were formalized before it was discovered that one more basic law should have preceeded them.
  - Rather than re-number the first two, the more basic law was given the number *zero*.
- So we have the 0th, 1st, and 2nd Laws of Thermodynamics.

THE 0TH LAW OF THERMODYNAMICS

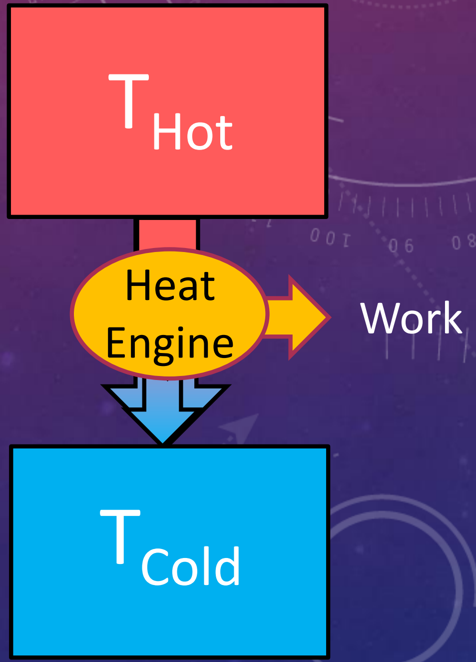
"If two objects are in thermal equilibrium with a third object, then they are in thermal equilibrium with each other."

- Re-statement: "If two objects are in equilibrium with a thermometer at the same reading, then they are at the same temperature."
- Consequence:
  - This law gives us a basis to determine what it means to be 'hotter than'.

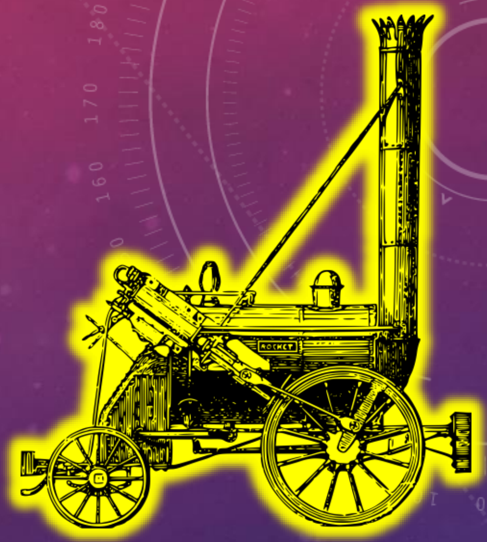
THE 1ST LAW OF THERMODYNAMICS

"Heat that naturally flows from a hot reservoir to a cold reservoir can be used to do mechanical work."

- The process that does this conversion is called a *heat engine*.
- Picture an object that has any temperature above 0 K.
  - It has internal energy (thermal energy).
  - This difference in internal energy from zero came from some combination of:
    - Heat that was added to the object (like holding it near a fire)
    - Work that was done on the object (like rubbing on it)
  - In equation form, this is: $\Delta Energy_{internal} = Work_{on} + Heat_{in}$
  - Work done *on* the object is the negative of work done *by* the object, so we can re-arrange the 1st Law to say: $Heat_{in} = Work_{by} + \Delta Energy_{internal}$
- Usually, the heat engine works at a constant operating temperature, so $\Delta Energy_{internal} = 0$
- The heat engine equation is: $Heat_{in} = Work_{by}$



HEAT ENGINE EXAMPLES

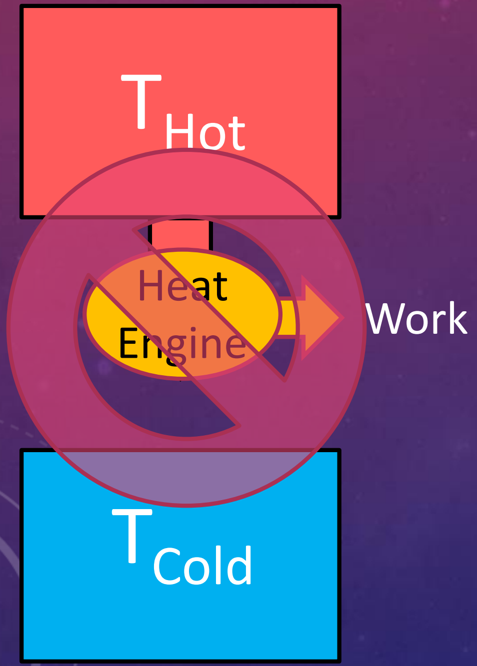


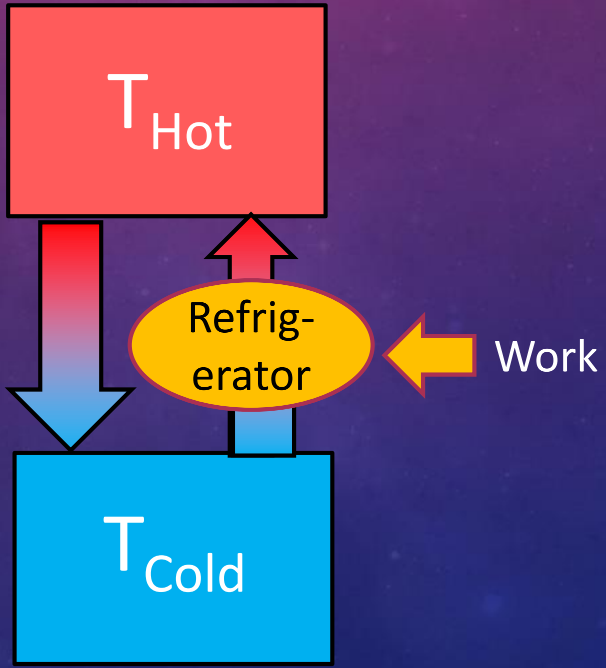
- Example: Steam engine
  1. Heat from burning wood or coal is used to boil water into steam.
  2. The expanding water pushes a piston, thus doing work and cooling down.
  3. The cooled steam condenses back into water.
  4. Back to step 1.
- Example: Internal combustion engine
  - Fuel is burned in the cylinder. The expanding gas does work on the piston, which turns the wheels and moves the car. The (still somewhat hot) expanding gas is vented out of the engine.
  - Car engine converts fuel into work, but much of the heat is lost to the environment.
- The *efficiency* of a heat engine is the ratio of (work done by the engine) to (heat from the hot reservoir).
  - Steam engine efficiency: ~40%
  - Internal combustion engine efficiency: gasoline - ~25%, diesel - ~ 40%

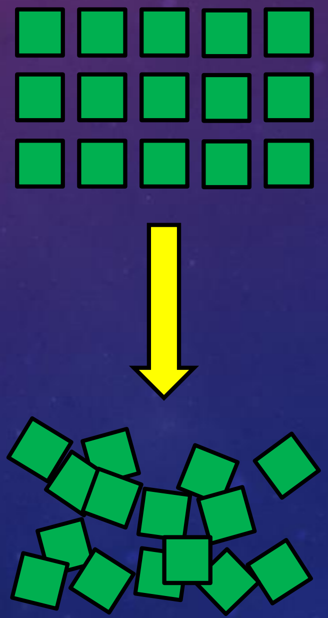
THE 2ND LAW OF THERMODYNAMICS

Three equivalent statements of the 2nd Law:

- “You cannot convert all of the heat flow into work. Some will be lost to the environment.”
- “Heat naturally flows from hot to cold. Work is required to reverse this.”
- “Isolated systems tend to go from order to disorder. (Entropy increases)”







REFRIGERATORS

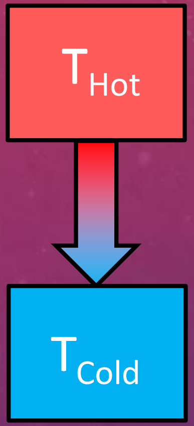
- How do refrigerators work?
  1. Energy comes from the power company, which is used to compress the coolant gas outside the refrigerator box, which generates heat in the room.
  2. The compressed gas is routed through a sealed circuit into the refrigerator box.
  3. The compressed gas is allowed to expand into a chamber, thus cooling it.
  4. The cold chamber absorb heat from the items in the box, warming the gas.
  5. The warm, expanded gas is routed outside the refrigerator box.
  6. The heat from the gas is vented into the room.
  7. Back to step 1.
- Consequence:
  - The inside of the refrigerator gets colder, but the room gets hotter; it absorbs the heat from inside the box plus the heat due to the work done by the compressor.

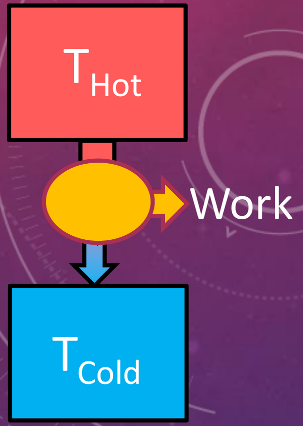
ENTROPY

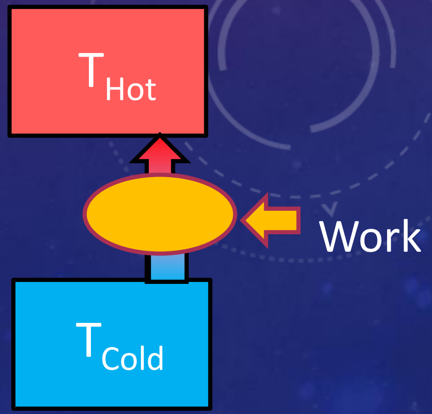
- Definition: Entropy is a measure of disorder. Heat causes entropy to increase.
- Example: Ice is highly ordered (low entropy). Adding heat turns it to water, which is somewhat ordered. Adding more heat turns it to steam, which is highly disordered (high entropy).
- Entropy on Earth is quite low (highly ordered), but we are not an isolated system.
  - The Sun's entropy is increasing (its order is decreasing) as hydrogen fuses to helium, releasing energy.
  - Energy flows to Earth through the vacuum of space.
  - Processes like life can take that energy and generate order from disorder (local entropy decreases).

ENTROPY

- The universe's overall entropy is increasing.
  - This will eventually lead to the 'heat death' of the universe.
- Heat increases entropy. It is easy to convert energy into heat (friction does this), but it is difficult to convert heat into useful work.
- Heaters have high efficiency because heat has a high entropy, and systems naturally move toward more entropy.
- Heating the inside of a car is easy, but cooling it (air conditioning) it is more complicated.
- A refrigerator lowers entropy inside the box, at the expense of more entropy (heat) in the room.







CONCLUSION

- Three laws describe how heat, work, and energy are related:
  - 0th Law: "If two objects are in thermal equilibrium with a third object, then they are in thermal equilibrium with each other."
  - 1st Law: "Heat that naturally flows from a hot reservoir to a cold reservoir can be used to do mechanical work."
  - The 2nd Law can be stated in several equivalent ways:
    - "You cannot convert all of the heat flow into work. Some will be lost to the environment."
    - "Heat naturally flows from hot to cold. Work is required to reverse this."
    - "Isolated systems tend to go from order to disorder. (Entropy increases)"

Heat engine efficiency < 100%

- *Entropy* is a term that describes disorder. Heat tends to disorder a system, which leads to increased entropy.
- Entropy can be decreased locally, but only at the cost of more entropy elsewhere, so the entropy of the universe increases overall.