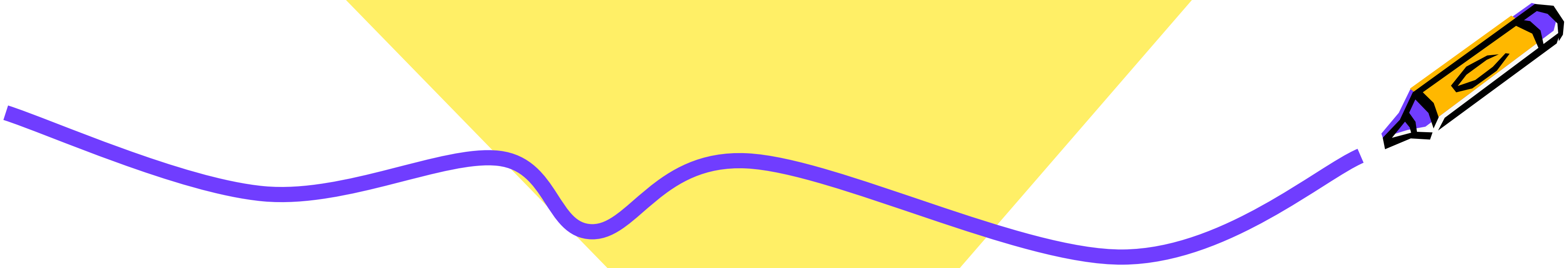
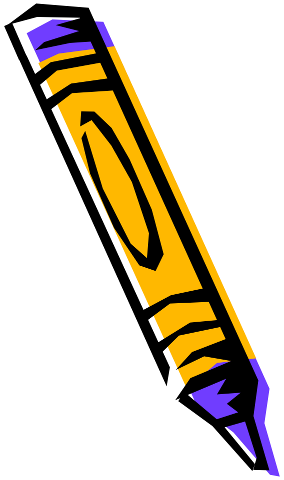
PHYSICS 102N
Spring 2022

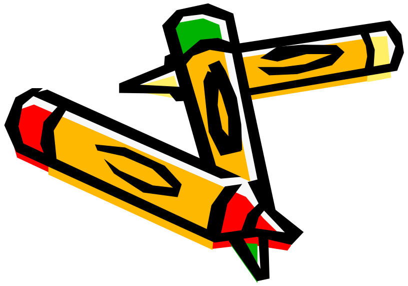
Week 5 Thermodynamics





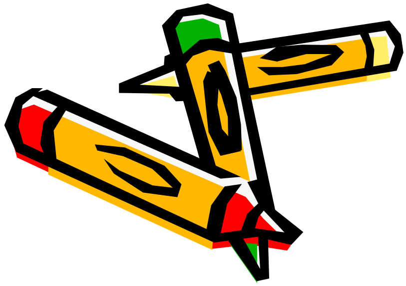
Putting it all together - Thermodynamics

- Study the relationship of work, heat and energy
- Understand relationships between density, pressure, temperature, energy
- Understand properties of gases, liquids, solids, phase transitions,…
- Understand heat engines and their limits
- new concept: Entropy (disorder <=> likelihood)



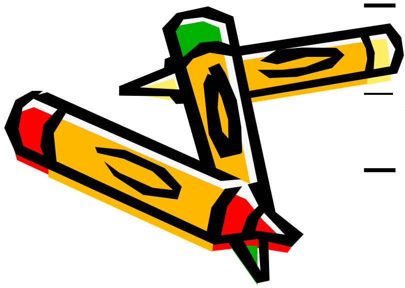
Work, Heat, Internal Energy

- **1st Law of Thermodynamics:** ΔE(internal) = Heat added **to** + Work done **on** system (Energy conservation; “You cannot win”)
- Examples:
  - Flame (or anything hotter than the system) => heat flow
  - Resistive heating, friction, impact heating, radiation…
  - Special case: Gases -> can do work by changing volume
    - move surface area A by a distance d inwards:
      - Need to exert force $F = P \cdot A$ on surface
      - Work done **on** system $Fd = P \cdot Ad = P(-\Delta V)$ (general rule)
      - either internal energy (temperature!) increases, or the system gives off heat. Example: Bicycle pump

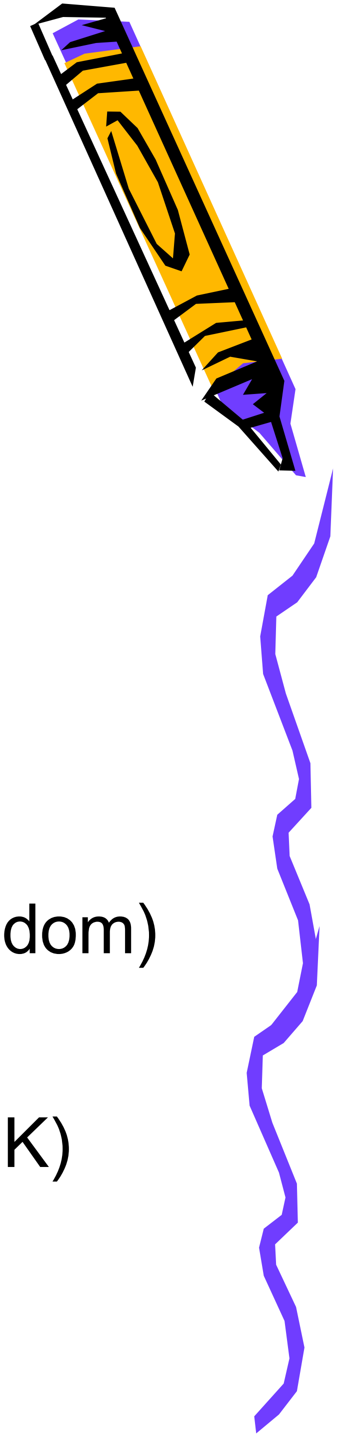


Consequences

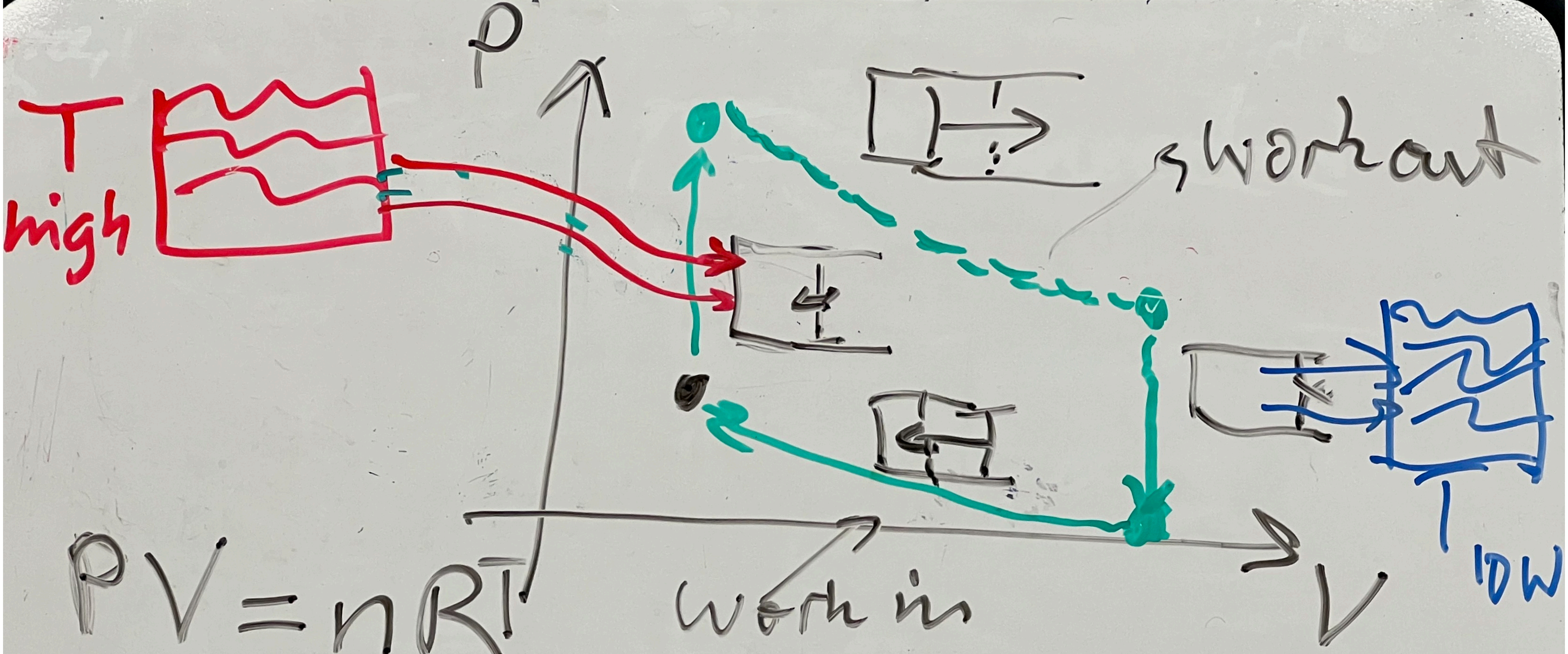
- If you add heat to a system while letting it do work (steam engine!), its internal energy will increase **less** (steam less hot)
- If you do **not** add heat to a system while letting it do work (releasing gas from a pressure bottle, air rising up and expanding) the system will lose internal energy (gets **colder!**) [Adiabatic Processes]
- Note: decreasing volume of gas increases pressure (Boyle’s Law); but temperature increases (if process is adiabatic) -> pressure increases even more!
  - $P \propto 1/V$ (Boyle’s Law: more frequent bouncing off walls)
  - $\Delta E(\text{internal}) = P(-\Delta V)$; $E(\text{intl})$ increases; T [in Kelvin] $\propto E(\text{intl})$
  - $P \propto T$ [in Kelvin] (more energy/molecule -> more and harder bouncing off walls)



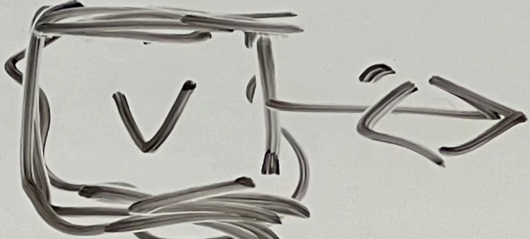
Putting it all together - The ideal gas law



- $PV = nRT$
  - P = pressure in Pascal, V = volume in m^3
  - n = number of mols, T = temperature in K
  - R = 8.3 J/mol/K universal (gas) constant
- $E_{\text{internal}} = {}^3/_2\, nRT$
  (1/2 for each direction of space = degree of freedom)
- $\Delta E_{\text{internal}} = P(-\Delta V)$ + Heat added
- Example: Volume of 1 mol of air at 0°C (273.15 K) and normal atmospheric pressure = 22.4 liters



$PV = nRT$

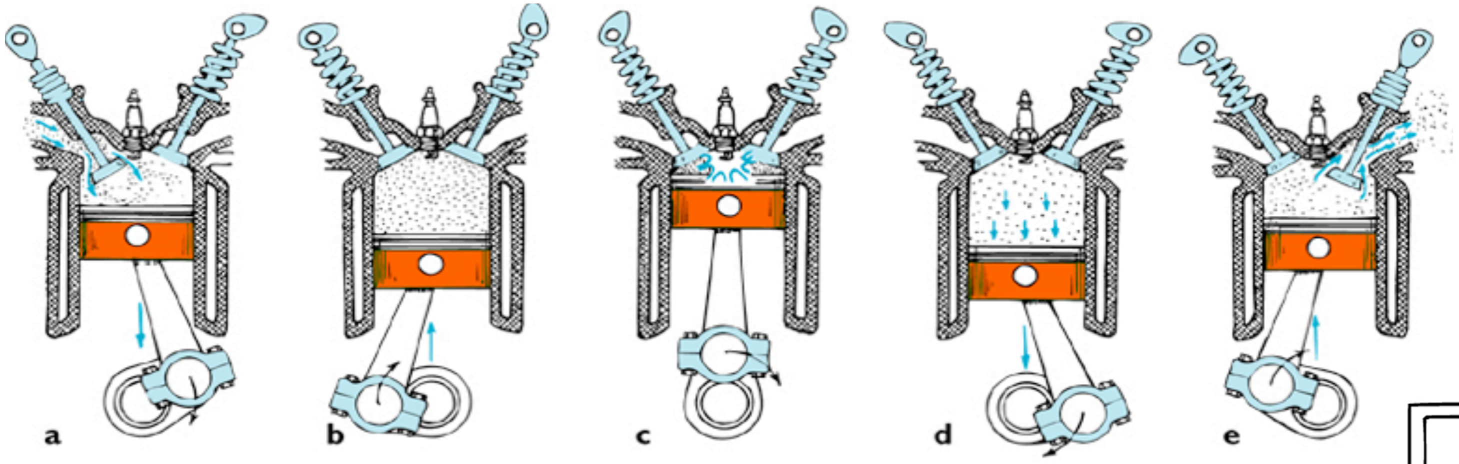


net work = eff. × heat picked up

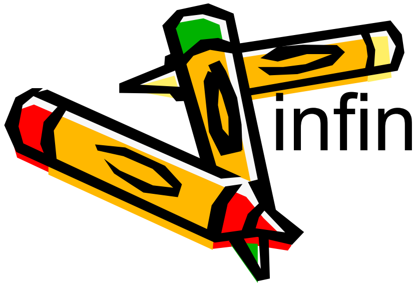
$$\text{eff} = 1 - \frac{T_{low}}{T_{high}}$$

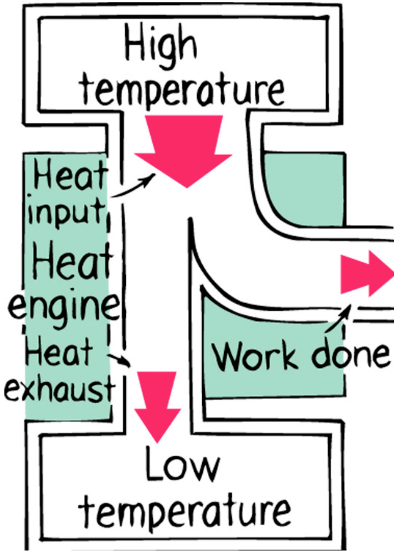
Heat engines

- Any device that converts **some** of the heat transferred to it into mechanical work
-

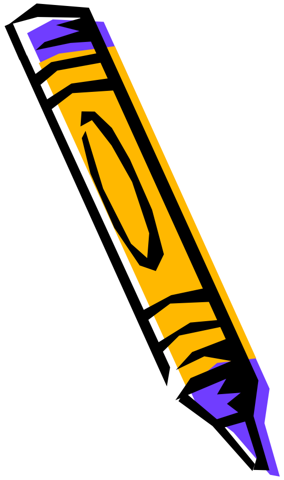


- Physicists dream engine:
  “Perfectly reversible Carnot Machine”
  (as efficient as possible, but runs infinitely slowly…)

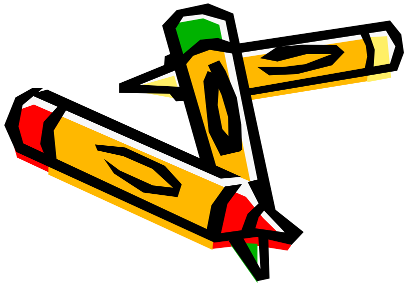




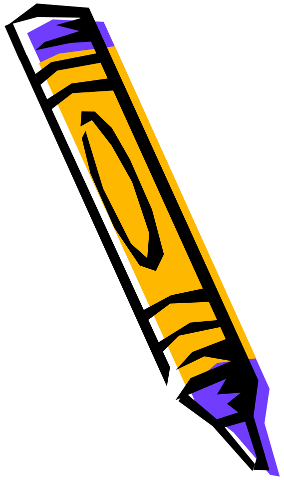
The hitch: Need low T “heat exhaust” (reservoir)



- Why?
  - Example hot gas turbine: You have to cool gas down **after** turbine to avoid “back pressure” (or machine comes to a halt)
  - Heat input at T_{hot}, heat exhaust at T_{cool} => at most 1 - $T_{\text{cool}}/T_{\text{hot}}$ of heat can be converted to useful work; rest ($T_{\text{cool}}/T_{\text{hot}}$) is exhaust heat (Sadi Carnot)
  - Car engine: exhaust simply gets blown into (colder) atmosphere; limit on efficiency (50% theor., 25% in practice)



Cooling engine (refrigerator, AC, heat pump) = heat engine in reverse: Move heat from cold reservoir to hot reservoir; requires mechanical energy input (less than generated heat output!)



=> 2nd Law of Thermodynamics

Many equivalent formulations - e.g. the following:

1. No machine can simply convert heat into work without exhausting heat into a colder reservoir; no machine can beat the Carnot efficiency
2. Heat can never flow spontaneously from cold to warm without external input of work
3. Entropy*) can never decrease; it always tends to increase over time (e.g. when heat flows from warm to cold); “you can’t get even”

*) Entropy = measure of disorder; the more different states a system can be in (compatible with “macroscopic” observables), the higher its entropy. All closed systems move towards maximal entropy

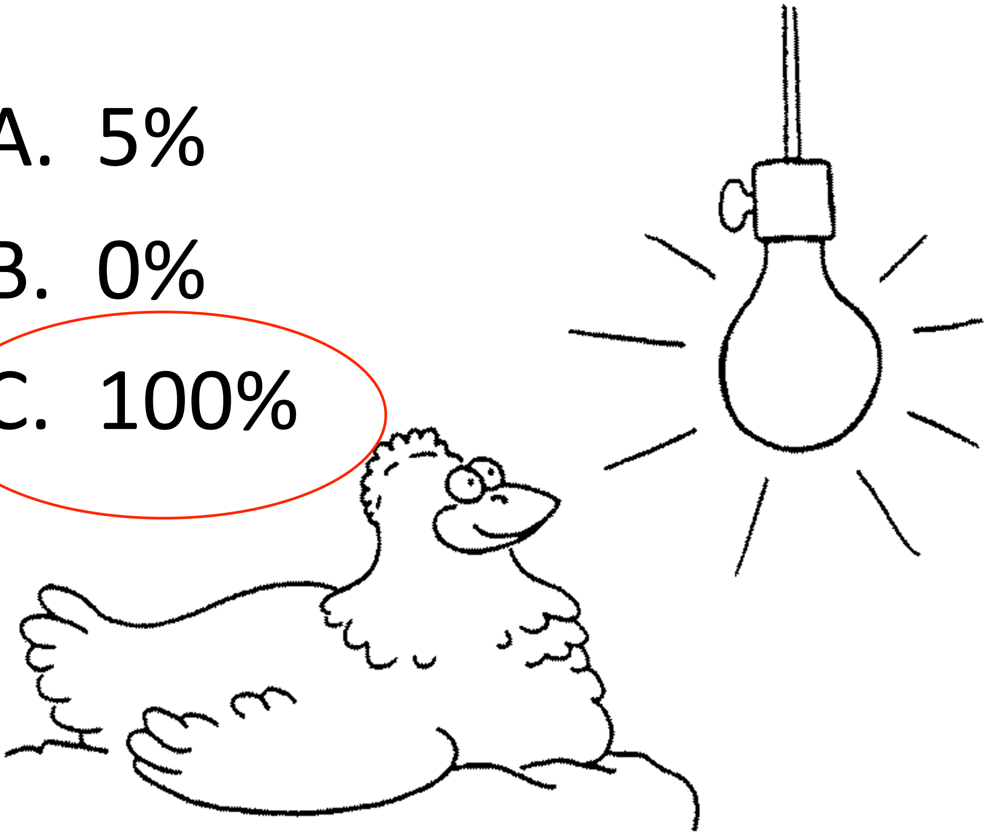
Q1

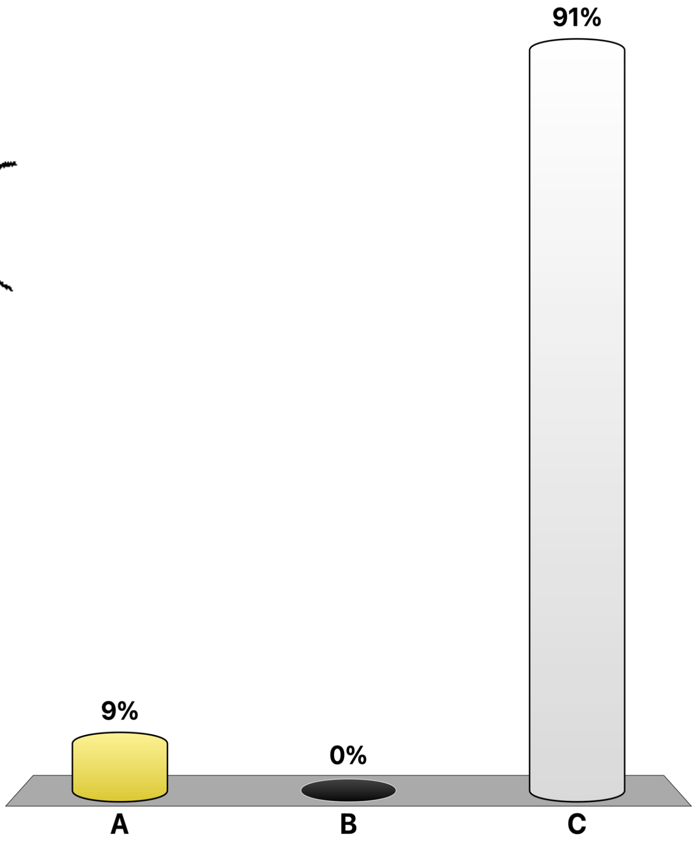
The efficiency of a common incandescent lamp for converting electrical energy into heat is about

A. 5%

B. 0%

[✓ C. 100%]





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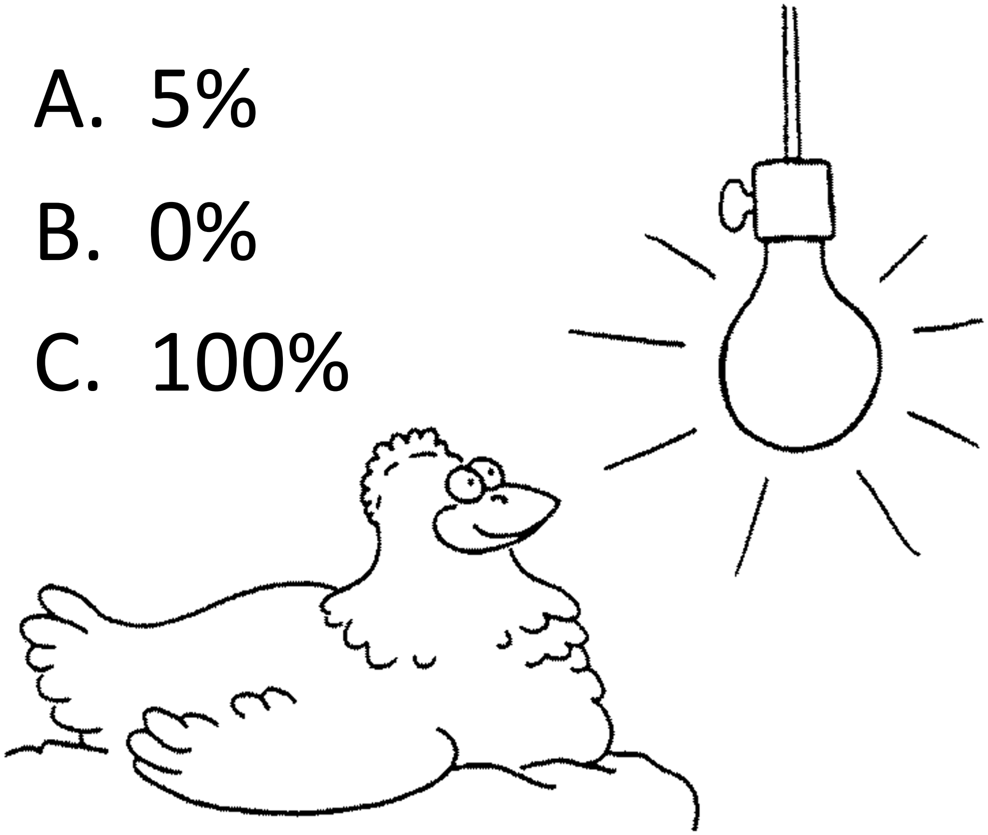

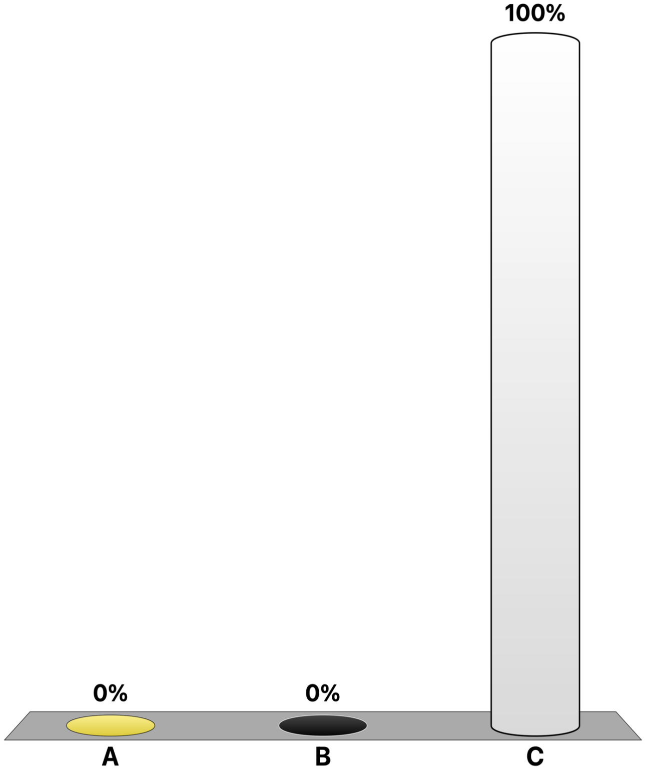

Q2

I can move heat from a cold reservoir to a warmer one using a heat pump. I can run my heat pump using a (perfect) heat engine running off the hot reservoir. Could I hereby transfer heat from the cold to the hot reservoir without any external work necessary?

A. No, because the heat engine would move the same amount of heat back to the cold reservoir

B. No, because it would violate the 2nd Law of Thermodynamics.

C. No, because this would decrease the entropy (disorder) in a closed system.

[✓ D. All of the above are true.]