1^{st} Law of thermodynamics

Select LEARNING OBJECTIVES:

- Identify the 1^{st} law of thermodynamics as an energy conservation statement.
- Understand that the 1^{st} law of thermodynamics describes changes in thermal energy of a system.
- Be able to determine if heat or work are relevant to a system.
- Understand that heat and work are both mechanisms for which a system to transfer energy.

TEXTBOOK CHAPTERS:

- Giancoli (Physics Principles with Applications 7^{th}) :: 14-1, 14-2, 15-1
- Knight (College Physics : A strategic approach 3^{rd}) :: 11.3, 11.4
- BoxSand :: First law of thermodynamics

WARM UP: Discuss the validity of the following statement. A large pot of water on a stove has a lot of heat.

OBJECTS AND SYSTEMS DO NOT POSSESS HEAT.

HEAT IS A GENERAL TERM FOR THE DIFFERENT MECHANISMS FOR TRANSFERRING THERMAL ENERGY BETWEEN OBJECTS/SYSTEMS

Let's review our current model of energy. It all began with defining a system. Once you defined your system you could ask the following questions:

- Are there any objects within my system that are moving up/down, left/right, in/out? If so include translational kinetic energy.
- Are there any objects within my system that are rotating? If so include rotational kinetic energy.
- Are any objects changing height within my system? If so include gravitational potential energy.
- Are there any springs within my system? If so include spring potential energy.
- Are there any motors within my system that are transforming energy within my system via internal work? If so include chemical energy and/or thermal energy.
- Is there any friction internal to my system? If so include thermal energy.

After these questions, we then looked for interactions with the environment to determine if there was any external work being done on the system.

In summary our work energy equation had the following form…

$$\Sigma KE_{Ti} + \Sigma KE_{Ri} + \Sigma U_i^g + \Sigma U_i^s + \Sigma E^{TH} + \Sigma E_i^{CHEM} + \Sigma W_{EXT} = \Sigma KE_{TF} + \Sigma KE_{RF} + \Sigma U_f^g + \Sigma U_f^s + \Sigma E_f^{TH} + \Sigma E_f^{CHEM}$$

(ΣKE_{Ti}) ARE ANY OBJECTS IN MY SYSTEM TRANSLATING? MOVING UP DOWN LEFT OR RIGHT?

(ΣKE_{Ri}) ARE ANY OBJECTS IN MY SYSTEM ROTATING?

(ΣU_i^g) ARE ANY OF THE OBJECTS IN MY SYSTEM CHANGING HEIGHT?

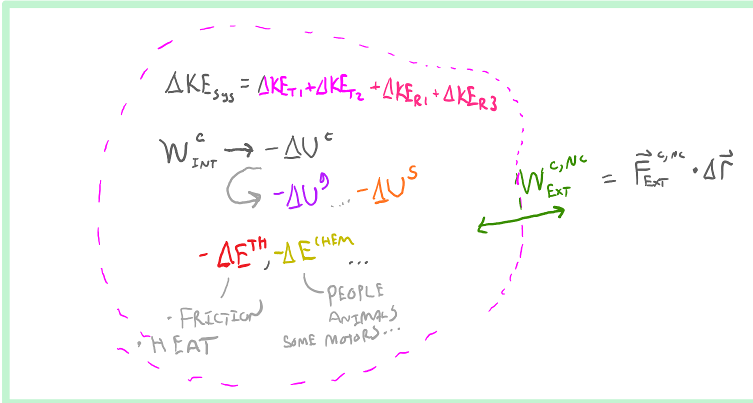
(ΣU_i^s) ARE THERE ANY SPRINGS IN MY SYSTEM?

(ΣE^{TH}) IS FRICTION INTERNAL? ALSO… ANY HEAT TRANSFER MECHANISMS?

(ΣE_i^{CHEM}) ARE THERE ANY LIVING CREATURES OR MOTORS IN MY SYSTEM THAT ARE TRANSFORMING ENERGY WITHIN THE SYSTEM e.g. MOTOR PROTEINS CAR ENGINES, MOTORS

(ΣW_{EXT}) ARE THERE ANY EXTERNAL FORCES DOING WORK ON THE SYSTEM? CAN BE FROM CONSERVATIVE OR NON-CONSERVATIVE FORCES

INCLUDE THESE INTERNAL FORMS OF ENERGY AT THE FINAL STATE



Recall that work is a mechanism for which objects within our system transform energy (internal work) and for which energy is transferred into or out of our system (external work). The basic idea is that a system has energy, and this energy can come in different forms. The total energy of the system is then the summation of each form of energy as shown below...

$$E^{SYSTEM}_{TOTAL} = \underbrace{KE_{TR} + KE_{ROT} + U^g + U^s}_{\text{MECHANICAL ENERGY } "E^{MECH}"} + E^{TH} + U^{CHEM} + E^{CREATE} + E^{NUCLEAR} + \ldots$$

MECHANICAL ENERGY "E^{MECH}": COLLECTIVE MOTION OF CENTER OF MASS "MACROSCOPIC"

E^{TH}: MICROSCOPIC RANDOM MOTION

U^{CHEM}: POTENTIAL ENERGY OF FOOD

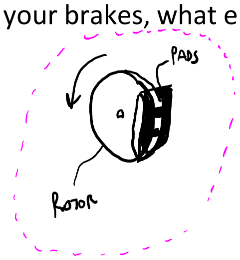
E^{CREATE}: $E = mc^2$

In ph201 we studied systems where mechanical energy was relevant. In future courses you might tackle systems where nuclear and mass energy equivalence principles are required. Chemical energy is typically covered in chemistry classes. Thus our goal for the rest of this term is to study the thermal energy of a system. We can do this by isolating our system such that the thermal energy is the only relevant physics. Thus if thermal energy is the only relevant physics we can write our work energy equation as...

$$E^{TH}_i + W_{EXT} = E^{TH}_f$$

$$\Delta E^{TH} = W_{EXT}$$

PRACTICE: When you step on your brakes mechanical processes result in calipers that squeeze brake pads together and pinch the rotating brake rotor. If you are traveling at a constant speed and suddenly apply your brakes, what energy transformations occur if the brake rotor and pads are your system?



SYSTEM: ROTOR + PADS

$$KE_{ROT,ROTOR} \longrightarrow E^{TH}_{ROTOR + PADS}$$

VIA

INTERNAL WORK FROM FRICTION $\} \; \vec{F}^F \cdot \Delta\vec{r}$

PRACTICE: Is it possible to increase the thermal energy of your brake rotors without doing work on them?

YES.... VIA HEAT

Q

Recall that work is a mechanism for which a systems can transfer energy into or out of the system (as well as transform energy within the system). But as the practice problem above suggest, we can also increase the thermal energy of a system without doing work on the system. Thus our current thermal energy equation isn't quite complete and needs to be updated. The new form is the following…

$$E_i^{TH} + W_{EXT} + Q = E_f^{TH}$$

$$\Delta E^{TH} = W_{EXT} + Q$$

The above energy equation is a statement of conservation of energy and known as the 1st law of thermodynamics. It says that if we do positive work on the system then the thermal energy will increase, or we can also heat the system to increase the thermal energy of the system. Then the increase in thermal energy of the system is dependent on both the sign and magnitude of work and heat.

IF $W_{EXT}(+)$ AND $Q(+)$; ENERGY INTO THE SYSTEM

IF $W_{EXT}(-)$ AND $Q(-)$; ENERGY LEAVES THE SYSTEM

IF $W_{EXT}(+ \text{ or } -)$ AND $Q(- \text{ or } +)$; DEPENDS ON $|W_{EXT}|$ AND $|Q|$

It helps to know the functional dependence of each quantity in the 1st law of thermodynamics so that you can visualize what is being done on the system.

$$\Delta E^{TH}(N,T) = W_{EXT}(P,V) + Q(T,S)$$

PRESSURE, VOLUME, TEMPERATURE, ENTROPY

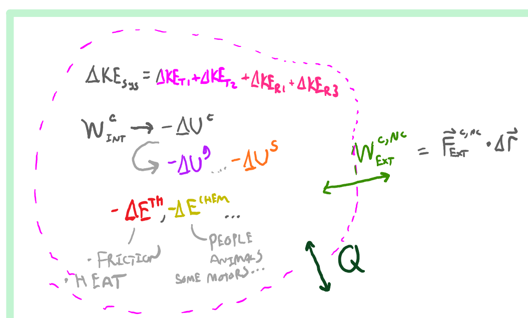
OR

$$W_{EXT}(\vec{F},\Delta\vec{r})$$

**Note: As you talk to other students and reference other resources you might come across a slightly different way to write the 1st law of thermodynamics. The only thing that is different is that other sources often put a minus sign in front of the external work term. What is the significance of this? Without the minus sign, the 1st law of thermodynamics describes the work done on the system and the heat added to the system. With a minus sign in front of the work the 1st law of thermodynamics describes the work done by the system on the environment and the heat added to the system.

PRACTICE: Heat is

1. a physical property that objects with T>0 possess.
2. the amount of thermal energy in an object.
3. the energy that moves (typically) from a hotter object to a colder object.
4. a measure of how hot an object is.
5. measured in J/s.
6. measured in J/m.



PRACTICE: Which of the following processes explicitly involve heat as the only mechanism for energy transfer?

(a) The brakes in your car get hot when you stop.
(b) A steel block is placed over a candle.
(c) Ice melting in a glass of water.
(d) A piston pushed into a cylinder of gas, increasing the temperature of the gas.

(e) A rigid cylinder of gas being pulled across a frictionless surface.

PRACTICE: In a certain process 16 kJ of work is done on a system while 12 kJ of heat is extracted. Does the system increase or decrease in temperature?

(a) Increase.
(b) Decrease.
(c) Stay the same.

$\Delta E^{th}(N,T) = W_{EXT} + Q$

$= 16\ kJ - 12\ kJ$

$\Delta E^{th} = +4\ kJ$

SO $\Delta E^{th} \uparrow$ AND $\Delta T \uparrow$

If the system consists of 3 moles of an ideal monatomic gas, how much does the temperature rise?

(a) 21 K
(b) 25 K
(c) 67 K
(d) 107 K
(e) 214 K
(f) 301 K

$\Delta E^{th} = \frac{3}{2} N k_B \Delta T = \frac{3}{2} nR\Delta T$

$\Delta T = \frac{2}{3}\frac{\Delta E^{th}}{nR} = 107\ K$

$\Delta T = T_f - T_i = 107\ K$

NEED T_i TO FIND FINAL TEMP.

PRACTICE: A paddle wheel frictionally adds thermal energy to 5.0 moles of an idea monatomic gas in a sealed isolated container. The paddle wheel is driven by a cord connected to a falling 2.0 kg object that transfers all the change in gravitational potential energy into work done on the gas. After the object falls 32 m, it is noticed that the temperature in the gas has risen by 8 K. Was heat added or removed from the gas during this event? If so, how much?

SYSTEM: MASS + GAS

$\Delta E^{th} = W + Q$
(+) (+) ?

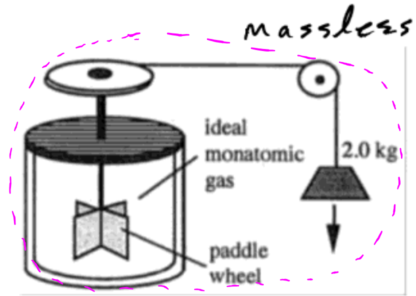
$Q = \Delta E^{th} - W$

$Q = \frac{3}{2} nR\Delta T - (mg|\Delta y|)$

$Q = 499\ J - (627\ J)$

$Q = -128\ J$

ENERGY REMOVED FROM SYSTEM.



*RECALL... EARLIER, $Q=0$
+ $\Delta y = 32\ m \rightarrow \Delta T = 10\ K$

PRACTICE: In a certain process a monatomic ideal gas does 3 kJ of work on the environment while 5 kJ of heat is added to the system. If the temperature of the gas increases by 300 °C, approximately how many moles are present in the gas?

(a) 0.5 moles
(b) 1.0 moles
(c) 1.5 moles
(d) 2.0 moles
(e) 2.5 moles

$\Delta E^{th} = W + Q$
(+) (−) (+)

$\frac{3}{2} nR\Delta T = -3\ kJ + 5\ kJ$

$n = \frac{2}{3}\frac{(2000\ J)}{R\Delta T} = 0.5$ moles

SYSTEM LOSES ENERGY (−)

$\Delta T(°C) = \Delta T(K)$

Ex: $T_f = 400°C$ $T_f = 673\ K$
$T_i = 100°C$ $T_i = 373\ K$
$\Delta T = 300°C$ $\Delta T = 300\ K$

ΔT BOTH 300 "UNITS"

ΔT BOTH 300 'UNITS'

Questions for discussion:

(1) If heat is removed from a system, must the temperature of the system decrease? Provide an example to support your answer.