L 20 Thermodynamics [5]

- heat, work, and internal energy
- the 1st law of thermodynamics
- the 2nd law of thermodynamics
- Heat engines
- order to disorder → entropy
- Electric cars and Hybrid cars

Heat, work, and internal energy

- The gas has internal energy, the temperature is the average KE,
- if heat is added its internal energy increases
- if the gas expands and does work on the atmosphere, its internal energy decreases
- Heat and work are forms of energy which can change the internal energy
- the 1st law of thermodynamics keeps track of the balance between the heat, work and internal energy of the gas

The First Law of Thermodynamics

- the change in internal energy of the gas
  \[ \Delta IE = Q_{in} - W_{out} \]
  - this is a simple energy accounting principle (law of conservation of energy)

work done by or on a gas

- if a gas does work (expansion) its internal energy goes down and so does its temp.
- if work is done on a gas (compression) its internal energy goes up and so does its temperature
- the internal energy of a gas can be changed by making or taking away heat or by having the gas do work or doing work on the gas

EXAMPLE

- What is the change in the internal energy of a gas if 3000 J of heat are added while the gas does 1000 J of work?
- change in internal energy
  \[ \Delta IE = Q_{in} - W_{out} = 3000 \text{ J} - 1000 \text{ J} = 2000 \text{ J} \]
  the internal energy increases by 2000 J

Meteorology and the 1st Law

- Air temperature rises as heat is added
- Air temperature rises (or falls) as pressure increases (decreases)
- In processes called adiabatic the amount of heat added or lost is very small
- As a parcel of air rises it expands adiabatically and its temperature decreases by about 10°C for each kilometer of elevation
Heat engines

- A heat engine is a device that uses heat (input, which you must pay for) to do work (output, which is useful).
- The central issue is how much of the heat taken in can be converted into work
- This is quantified by the engine efficiency
- The amount of heat that can be converted to work is limited by the 1st law
  \( \Rightarrow \text{you can't get more out than goes in} \)

The 2nd Law of Thermodynamics

- Not all of the heat can be converted into work.
- try to understand the difference between work energy and heat energy
- give the block a push– it will stop due to friction
- the kinetic energy is converted to HEAT
- but, I cannot make the block move by heating it!

Heat – disordered energy

- When an object is heated, the energy of all of its molecules is increased.
- however, the molecules do not all move in the same direction \( \Rightarrow \) they move about in all directions \( \Rightarrow \) this is what we mean by disordered (or thermal) energy
- on the other hand, if we want to get the system to do some useful work, we want it to move in some particular direction

order to disorder

- All naturally occurring processes go in the direction from order to disorder
- ice melts when placed in water; it never gets colder and the water gets warmer
- ice, the solid state of H₂O is more ordered than water, the liquid state
- in a solid all the molecules are lined up in a regular (ordered) array; there is less order in the liquid state, and even less in the gaseous state
- when salt is put in water it dissociates; crystals of salt never spontaneously form in a salt water solution

Work is ordered energy, heat is disordered energy

- It is possible to convert some of the random energy to do useful work
- when a gas is allowed to expand, some of its random thermal energy is converted into work
- the 2nd law explicitly prohibits all of the heat from being converted into work
- this is a fact of nature \( \Rightarrow \) the way things are!

Heat Engines

- an engine operates in a cycle
- fuel is burned to make heat
- some of the heat is converted into work
- the heat that is not converted to work is removed to bring the system back to the beginning state (cycle)
- since the system is always returned to the original state the change in internal energy is ZERO
- First Law \( \Rightarrow \) \( Q_{in} = W_{out} + Q_{out} \)

\[ \text{efficiency} = \frac{W_{out}}{Q_{in}} \]
1st and 2nd Laws of Thermodynamics

- For an engine operating in a cycle the 1st law requires that:
  \[ \text{work out} = \text{heat in} - \text{heat out} \]
- the 2nd law says that it is impossible to make the heat out \( (Q_{\text{out}}) = 0 \) ➔ not all the heat energy can be converted into work, some must be discarded – thermal waste
- engine efficiency = work out / heat in
- no engine can be 100% efficient ➔ this is a law of nature!

Heat engine example

A heat engine, operating in a cycle, absorbs 10,000 J of energy from a heat source, performs work, and discards 6,000 J of heat to a cold reservoir.

(a) how much work is performed?
(b) what is this engine’s efficiency?
(c) what is the change in internal energy of this engine?

(a) \( W_{\text{out}} = Q_{\text{in}} - Q_{\text{out}} = 10,000 \text{ J} - 6,000 \text{ J} = 4,000 \text{ J} \)
(b) efficiency\( = \frac{W_{\text{out}}}{Q_{\text{in}}} = \frac{4,000}{10,000} = 0.4 \) or 40 %
(c) \( \Delta IE = 0 \), the change in internal energy for an engine operating in a cycle is ZERO

Second law of thermodynamics

I. (Kelvin) It is impossible to have a heat engine that is 100 % efficient ➔ Not all of the heat taken in by the engine can be converted to work

II. (Clausius) In a spontaneous process, heat flows from a hot to a cold substance ➔ Work must be done to move heat from a cold to a hot substance.

refrigerators and air conditioners

- Heat pump (heat engine in reverse)
- You can make heat flow backward (cold to hot) only if there is an input of work
- in an air conditioner or refrigerator, this work must be supplied by electricity.

internal combustion engine

at cruising speeds this cycle happens at 3000 times/min (50 /s)
Electric cars
• Propelled by a battery-powered electric motor – does not need gasoline
• No tailpipe emissions – reduces urban pollution and greenhouse gases
• Batteries must be charged, but electric power is provided by domestic fuel sources
• Chevy Volt – charged on $1.50/day
• Range limited by battery charge
• Poor acceleration
• Expensive

Hybrid Automobiles
Combination of 2 different systems
• A hybrid car propels itself on fuel or batteries
• It combines electrical and mechanical power
• It switches easily between fuel, batteries, or both
• It can recharge its batteries during braking. In a conventional auto, much of the kinetic energy is dissipated as heat during braking.
• It can turn its engine off when not needed
• It can restart its engine quickly and easily
• Excellent fuel economy up to 50 mpg (Toyota Prius)

Hybrid: gas engine + electric motor

Disadvantages of hybrid cars
• Expensive
• Limited top speed
• Poor acceleration (0 – 60 mph in 10 s)
• Mechanically complicated
• Batteries must be replaced; discarded batteries pose an environmental issue

But, hybrid cars are a new technology that is constantly being improved