Overview

Thermodynamics is the study of energy and its transformations.

The 1st law of thermodynamics says that energy cannot be created or destroyed. In other words, energy is conserved.

The 2nd law of thermodynamics says that even though energy is conserved, you can't have your energy just any way you like it.

I. Concepts and Definitions (Ch.1)

II. Transfer of Energy by Heat and Work. Conservation of Mass and Energy for Closed Systems (Ch. 2, 4)

III. Properties of Pure Substances (Ch. 3)

IV. Conservation of Energy for Closed Systems (Ch. 4)

IV. Conservation of Mass and Energy for Open Systems (Control Volumes) (Ch. 5)

V. The Second Law (Ch. 6)

VI. Entropy and the Entropy Balance (Ch. 7)

VII. Power and Refrigeration Cycles (introduction to Ch. 9, 10, 11)

THERMODYNAMICS TOOLBOX

Models of Working Substances
- Ideal or perfect gas
- Real gas
- Incompressible substance
- Phase-change fluids
- Mixtures

Concepts and Definitions
- Properties (intensive, extensive)
- System (boundary, open, closed)
- Surroundings

Conservation Laws
- Energy is conserved (First Law)
- Mass is conserved
- Momentum is conserved

Second Law
- An isolated system will tend to a state of equilibrium
- Certain processes are possible, others are not

Universal Balance Equation for Any Extensive Property

Accumulation = transport + generation

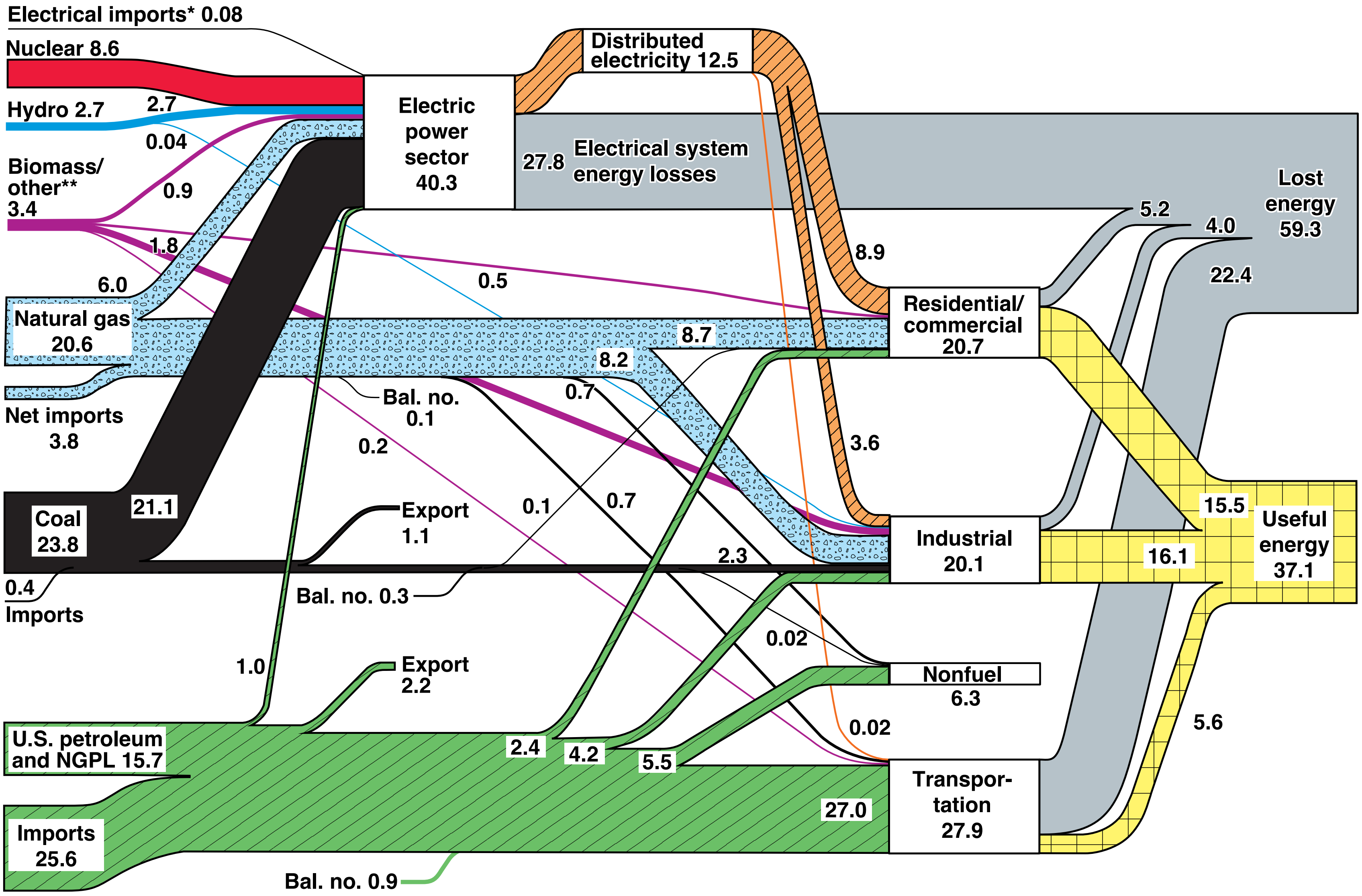
Accumulation form:

$$\begin{bmatrix}\text{final}\\ \text{amount}\end{bmatrix}-\begin{bmatrix}\text{initial}\\ \text{amount}\end{bmatrix}=\begin{bmatrix}\text{amount}\\ \text{entering}\end{bmatrix}-\begin{bmatrix}\text{amount}\\ \text{leaving}\end{bmatrix}+\begin{bmatrix}\text{amount}\\ \text{generated}\end{bmatrix}-\begin{bmatrix}\text{amount}\\ \text{consumed}\end{bmatrix}$$

Rate form:

$$\begin{bmatrix}\text{rate of}\\ \text{change}\end{bmatrix}=\begin{bmatrix}\text{rate of}\\ \text{transport in}\end{bmatrix}-\begin{bmatrix}\text{rate of}\\ \text{transport out}\end{bmatrix}+\begin{bmatrix}\text{rate of}\\ \text{generation}\end{bmatrix}-\begin{bmatrix}\text{rate of}\\ \text{consumption}\end{bmatrix}$$

U.S. Energy Flow Trends – 2002
Net Primary Resource Consumption ~103 Exajoules



Source: Production and end-use data from Energy Information Administration, *Annual Energy Review 2002.*
*Net fossil-fuel electrical imports.
**Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.

June 2004
Lawrence Livermore
National Laboratory
http://eed.llnl.gov/flow

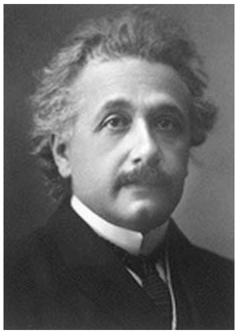
One Physicist's View of Thermodynamics

- Thermodynamics is a funny subject. The first time you go through it, you don't understand it at all. The second time you go through it, you think you understand it, except for one or two points. The third time you go through it, you know you don't understand it, but by that time you are so used to the subject, it doesn't bother you anymore.

Arnold Sommerfeld
1868 – 1951
Mathematician and physicist

Another Physicist's View

- [A law] is more impressive the greater the simplicity of its premises, the more different are the kinds of things it relates, and the more extended its range of applicability. Therefore, the deep impression which classical thermodynamics made on me. It is the only physical theory of universal content, which I am convinced, that within the framework of applicability of its basic concepts will never be overthrown.



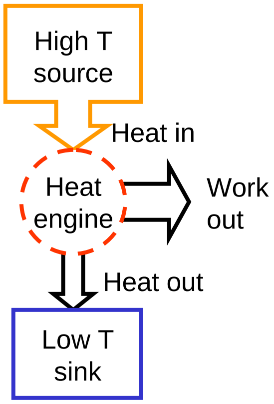
Albert Einstein
1879 – 1955
Mathematician and physicist

I. Concepts and Definitions

A. Applications of thermodynamics
  1. Electrical engineering
    a. theory of semiconductors (statistical thermodynamics)
    b. cooling of electronic equipment
  2. Civil and environmental engineering
    a. heating and cooling of buildings
    b. power requirements for pumps and blowers
    c. waste water treatment
    d. thermal pollution and global warming
  3. Mechanical and chemical engineering
    a. refrigeration and air conditioning
    b. engines, power generation
    c. process engineering

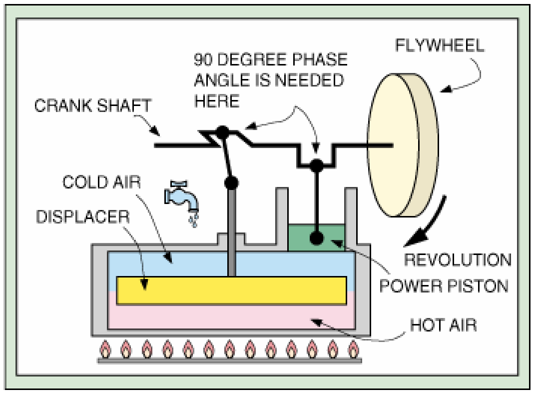
I. Concepts and Definitions

B. How thermodynamics got started - heat engines
  1. Thermodynamics began with the study of how you do work with heat
    a. Can we get heat to do work in a more efficient way?
    b. What substance will make the best engine?
  2. Heat engines operate on a cycle and they <u>must</u> reject heat to the surroundings. Why?



I. Concepts and Definitions

3. Example of a heat engine - the Stirling engine (p. 503 of text)



The air inside the cylinder is alternately heated and cooled. This causes it to expand and contract, moving the power piston up and down. The flywheel is used to store energy to help move the displacer. The displacer moves the air in the cylinder from one side to another.

Drawing from http://www.bekkoame.ne.jp/~khirata/indexe.htm
(last accessed 7 July 2005)

I. Concepts and Definitions

C. An example of what we mean by conservation of energy

Borrowed from Richard Feynman's, The Character of Physical Law. A father gives daughter 28 indestructible blocks and leaves her to play in her room. Each block weighs 3 oz. The next day he finds only 27 but discovers one has been tossed out the window. To keep track of the blocks, you must account for what crosses the walls. One day he notices only 25 blocks and Sally refuses to let him look inside her jewelry box. The empty box weighs 16 oz. So,

$$No.\ of\ blocks\ seen + \frac{wt.\ of\ box - 16\ oz}{3\ oz} = 28$$

This works for a while. Then a few days later the sum doesn't add up, but the level of dirty water in the sink has risen. The initial water level was 6 in and one block raises the level by ¼ in. So,

$$No.\ of\ blocks\ seen + \frac{wt.\ of\ box - 16\ oz}{3\ oz} + \frac{ht.\ of\ water - 6\ in}{1/4\ in} = 28$$

I. Concepts and Definitions

C. An example of what we mean by conservation of energy (cont.)

(Borrowed from Richard Feynman's, <u>The Character of Physical Law</u>)

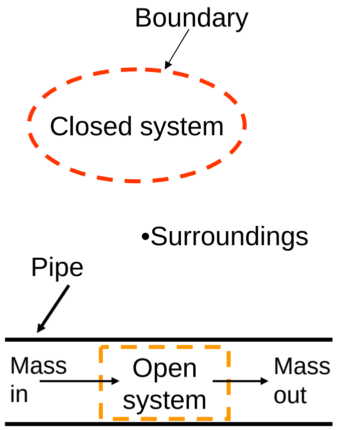
So we have a mathematical formula and a set of rules for calculating a number for each of the many different kinds of energy. If we add up all the numbers, they always give the same total.

The conservation of energy is purely mathematical and is consequently abstract. No one knows why energy is conserved and we cannot define energy. But we don't need to know because we can define a mathematical formula and a set of rules for all of the different forms of energy and this allows us to make useful calculations.

I. Concepts and Definitions

D. Closed and open systems - definitions

1. A **system** is that part of the universe chosen for study.
2. A **closed system** is a fixed amount of material. No mass crosses the boundary. Example: the contents of an unopened bottle of orange juice.
3. An **open system** is a selected region in space. Mass crosses the boundary. Example: your body.
4. No mass or energy crosses the boundary of an **isolated system**. Example: the contents of an ice chest.



I. Concepts and Definitions

E. Forms of energy (see p. 53-59)

1. we can only measure changes in energy
2. **internal** (kinetic and potential energy of molecules and atoms within the system). The internal energy will change with pressure, phase, temperature, and chemical composition.
3. **kinetic** (movement of the center of mass of the system)
4. **potential** (relative position of system in gravitational field, standard gravity, g = 9.81 m/s^2)
5. **total energy** $\underline{E = U + KE + PE}$

U = internal energy (J)
u = specific internal energy, U/m (J/kg)

$$KE = \frac{1}{2} mV^2 \ (J)$$

$$V = velocity \ (m/s)$$

$PE = mgz$ (J)

I. Concepts and Definitions

6. Energy is conserved. We can also say that the change in the total energy must be zero. The total energy is the sum of the energy of the system and surroundings. Then in integrated form,

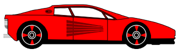
$$\boxed{\Delta E_{total} = \Delta E_{system} + \Delta E_{surroundings} = 0}$$

We can also write this in rate form:

$$\boxed{\frac{dE_{total}}{dt} = \frac{dE_{system}}{dt} + \frac{dE_{surroundings}}{dt} = 0}$$

I. Concepts and Definitions

7. **Example** - you and your car (m = 1500 kg) are traveling at 60 km/h (37 mph) when the light suddenly changes to red and you come to a stop. (1) How much energy is “wasted”? (2) Where does this energy go?
   - a. Approach
     - i. define a system (car + surroundings)
     - ii. ΔE = 0 because energy is conserved
   - b. ΔU = - ΔKE = 208.3 kJ



60 km/h → 0 km/h

$$\Delta E = \Delta U + \Delta KE + \Delta PE = 0$$

$$\text{Assume} \;\; \Delta PE = 0$$

$$\text{Then} \;\; \Delta U = -\Delta KE$$

$$\Delta KE = KE_2 - KE_1 = \frac{1}{2} m\left(V_2^2 - V_1^2\right)$$

$$= \frac{1}{2} 1500\,kg\left(0^2 - 16.67^2\right) m^2 / s^2$$

$$= -2.083x10^5 \frac{kg\;m^2}{s^2} = -2.083x10^5\; J$$

$$= -208.3\; kJ$$

The KE has been converted into internal energy, U. The increase in U will show itself as an increase in the temperature of the car (brakes, wheels, and tires) and the surroundings (pavement and air).