Thermodynamics of Materials

2nd Lecture

2008. 3. 5 (Wed.)

Temperature Scale

After thermometers were invented, different thermometers used different temperature scales.
→ Standardization was necessary.

Invent it yourself with the background knowledge of the 17th century.
What are the most important factors?

1. Fixed points
2. Within temperature domain of practical interest

G.D. Fahrenheit

(Gdansk 1686, Hague 1736)

Three fixed points

1. Zero degrees at the temperature of an ice, water, and salt mixture in equal amounts.
2. 32 F at the equil. temperature of the water-ice mixture.
3. 96 F at the temperature in the mouth or under the armpit of a living man in good health.

After Fahrenheit died in 1736, scientists calibrated his model of thermometer using 212 degrees, the temperature at which water boils, as the upper fixed point.
When the Fahrenheit thermometer was recalibrated, normal human body temperature registered 98.6 rather than 96.

A. Celsius

(Uppsala 1701, Uppsala 1744)

For his meteorological observations he constructed his world famous Celsius thermometer, with 0 for the boiling point of water and 100 for the freezing point.

After his death in 1744 the scale was reversed to its present form.

From the scientific point of view the most important contribution to the modern temperature scale is due to Celsius because of his careful experiments on the fixed points.

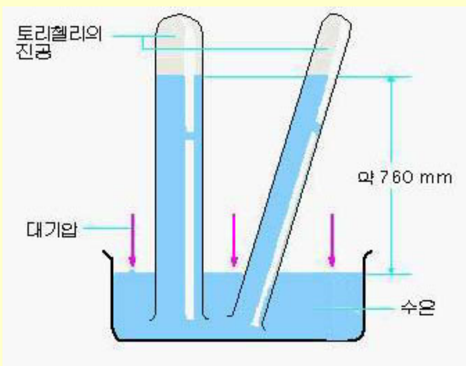
2. Pressure

What is pressure?

How can you measure atmospheric pressure with the background knowledge of the 17th century?

Evangelista Torricelli
(Faenza 1608 – Florence 1647)

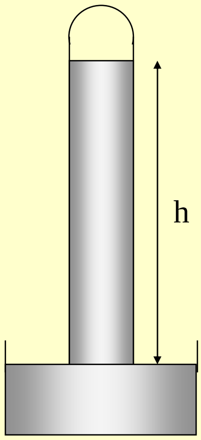
http://nl.wikipedia.org/wiki/Vacu%FCm



http://cont1.edunet4u.net/cobac2/scientist/Torricelli.html

Pressure

- **Force/Area**
- **units**
  - **Pascal = Newton/m^2 = Joule/m^3**
  - **atmosphere = 101325 Pa = ~ 0.1 MPa**
  - **bar = 100000 Pa**
  - **atmosphere = 760 mm Hg = 760 torr**



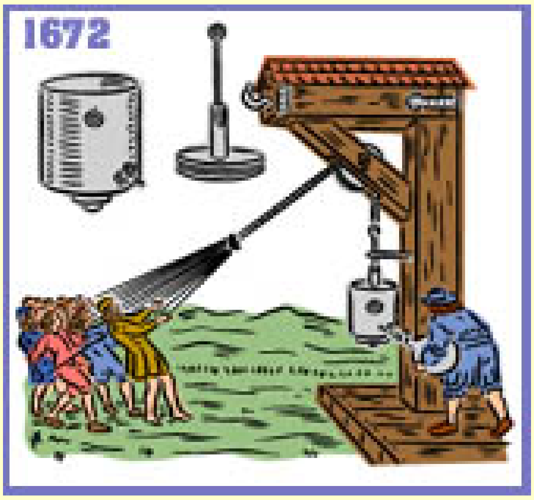
What do we have in the upper part of the flask?

→ **discovery of vacuum**

***Guericke's famous experiment with the Magdeburg hemispheres* in 1654.**

Otto von Guericke was mayor of Magdeburg, Bavaria.

http://chem.ch.huji.ac.il/~eugeniik/history/guericke.html



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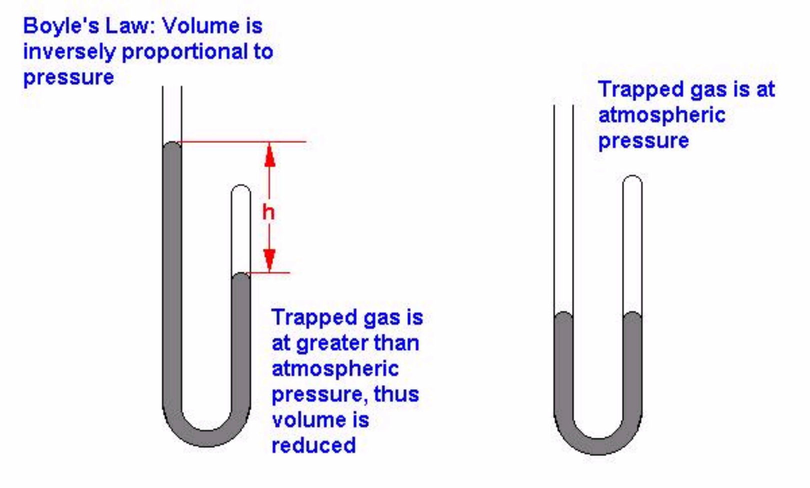
Robert Boyle (1627-1691)

"J-Tube" experiment



http://www.chem.uidaho.edu/~honors/gas.html

Robert Boyle (1627-1691) "J-Tube" experiment

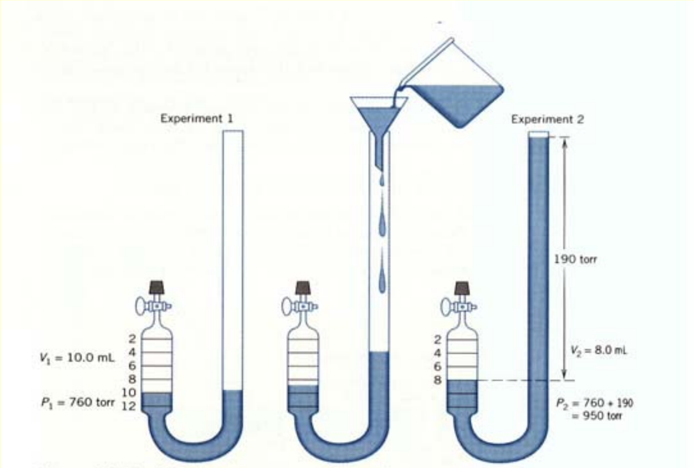
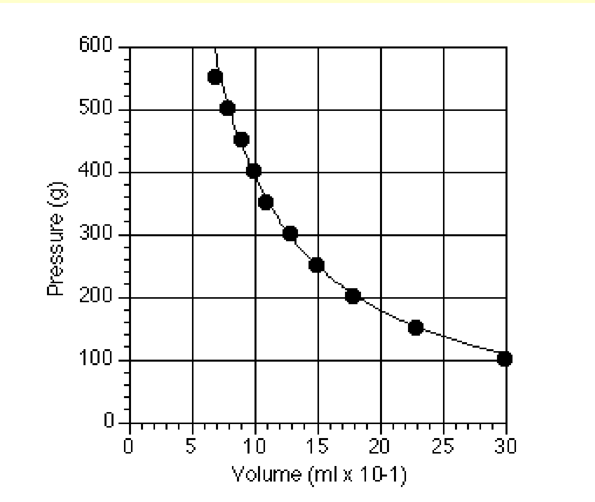


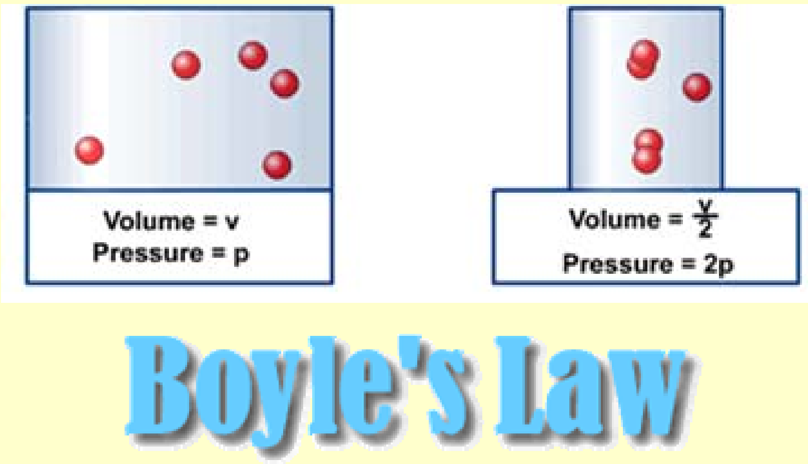
Figure 9-4 Boyle's Law Apparatus Addition of mercury in the apparatus causes an increase in pressure on the trapped gas. This leads to a reduction in the volume.

www.syjy.com.cn/jxzyk/ sck/czhx/czhx10/h10-62e.JPG



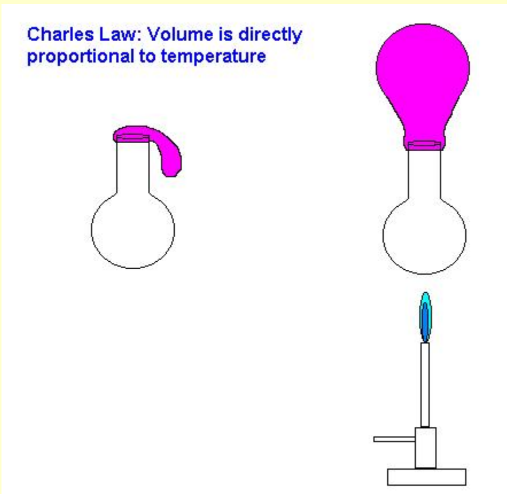
PV = constant → Boyle's Law

(at constant T)

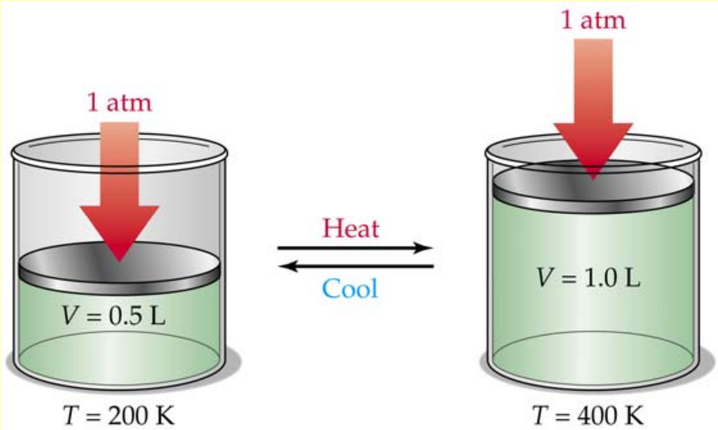


www.ngfl-cymru.org.uk/.../ Introduction/front.gif

Jacques Charles (1746-1823)



http://www.chem.uidaho.edu/~honors/gas.html



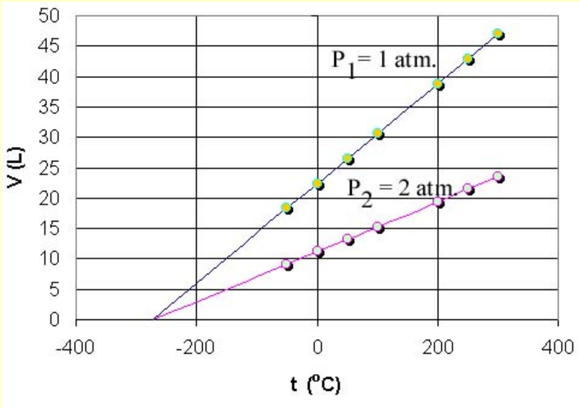
How far the volume can decrease with decreasing temperature?

Joseph Louis Gay-Lussac

By excluding water vapor from the apparatus and by making sure that the gases themselves were free of moisture, he obtained results that were more accurate than had been obtained previously by others.

He concluded that equal volumes of all gases expand equally with the same increase in temperature, indicating that thermal expansion coefficients of all permanent gases are the same.

He calculated the temperature of zero gas volume to be – 266.66^{o}C.

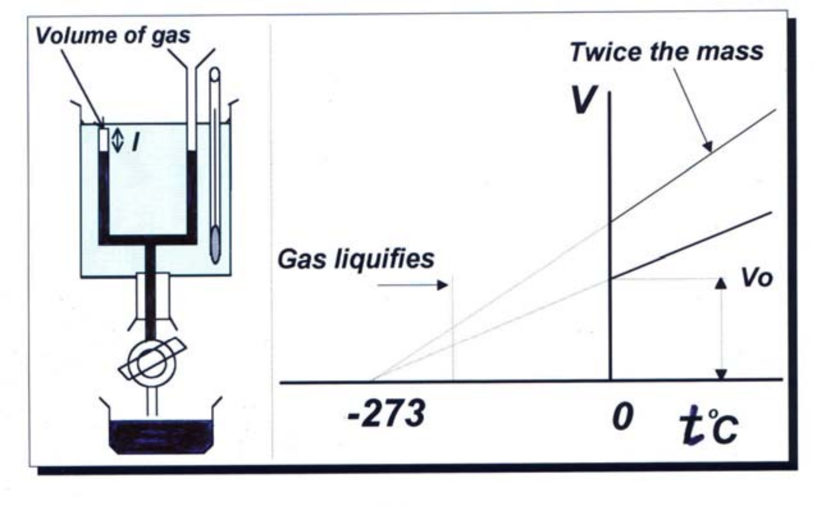


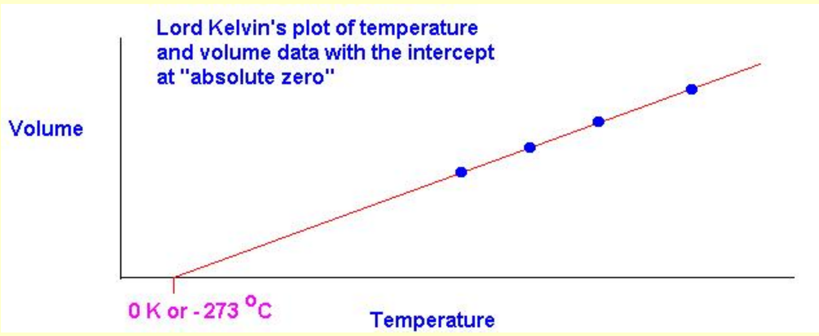
What is the thermal expansion coefficient of ideal gas?

$$V = V_o(1 + \alpha t)$$

At - 273^{o}C, ‘V’ should be zero.

$$\alpha = \frac{1}{273}$$





http://www.chem.uidaho.edu/~honors/gas.html

How do you interpret Gay-Lussac's data:
thermal expansion coefficients of all permanent gases are the same?

Amadeo Avogadro interpreted Gay-Lussac's data

Avogadro's hypothesis:
Equal volumes of gases at the same temperature and pressure contain equal numbers of molecules

$$V = constant \times n$$

Gay-Lussac combined his law with Boyle's law of ideal gases and produced the Ideal Gas Law.

$$PV = nRT$$

Why does temperature drop
in adiabatic expansion?
(physical meaning)

How do we make artificial snow?
(ex. in the ski resort)

Pierre Simon Laplace (1749-1827)

Phenomenon observed in Bohemian salt mine
Compressed air was released from a water pipe
and the air was released from a water pipe and the air
became so cold that snow condensed out of it.

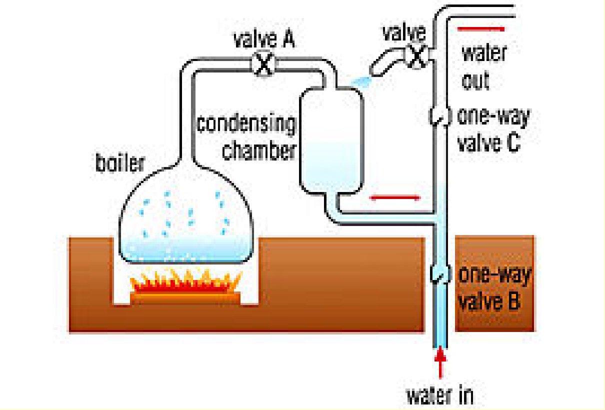
Adiabatic Effect

$$PV^{\gamma} = Const.$$

$$\gamma = \frac{C_P}{C_V}$$

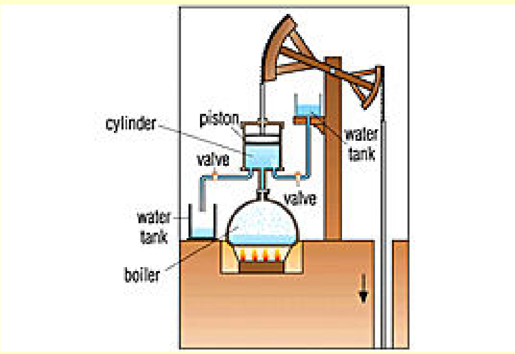
How can you make rough vacuum easily and repeatedly for removing water in the mine?

Savery’s Steam Pump (1698)



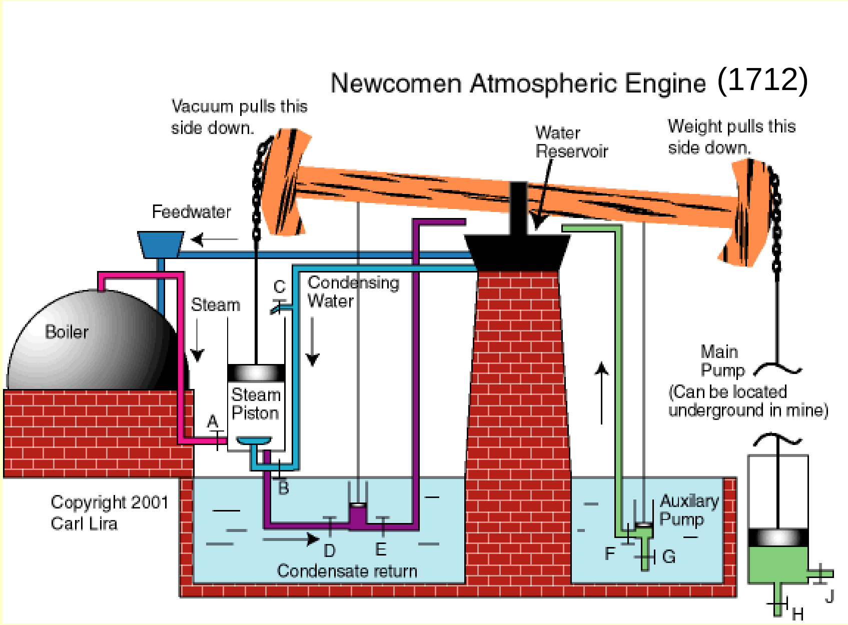
(Image © Research Machines plc)

Newcomen’s Engine (1712)



(Image © Research Machines plc)

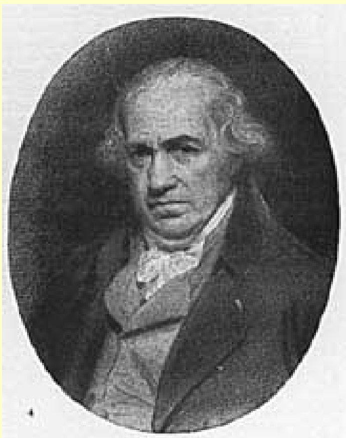
Thomas Newcomen's steam engine, invented in 1712, was the first practical steam engine and was used to power pumps in the tin mines of Cornwall and the coal mines of northern England. Steam from the boiler entered the cylinder as the piston moved up (pulled by the weight of a wooden beam). Water from a tank was then sprayed into the cylinder, condensing the steam and creating a vacuum so that air pressure forced down the piston and activated the pump.

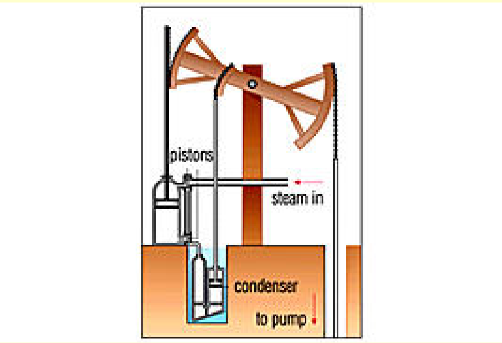


http://www.egr.msu.edu/~lira/supp/steam/

James Watt's Engine (1769)

James Watt (1736 -1819)





James Watt's steam engines, dating from 1769, were an improvement on that of Thomas Newcomen in that they had a separate condenser and permitted steam to be admitted alternately on either side of the piston.

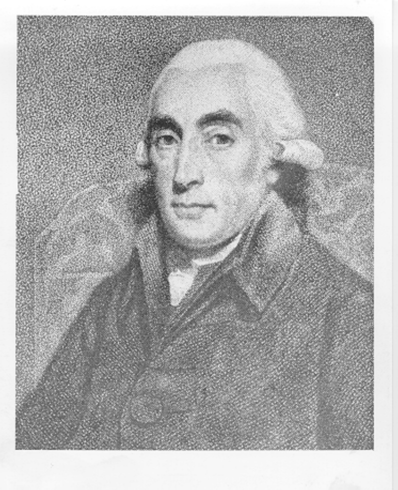
(Image © Research Machines plc)

One Sunday afternoon in May 1765
Watt went for a walk on Glasgow Green.
As he put it, 'I had not walked further
than the golf-house when the whole thing
was arranged in my mind':
the engine needed a separate condenser.

http://www.bbc.co.uk/cgi-bin/education/betsie/parser.pl/0005/www.bbc.co.uk/history/historic_figures/watt_james.shtml

Those who make engines
are called “engineer”.

Joseph Black
Lecturer in Chemistry, Glasgow University, 1756-66



fundamental work
on latent
and specific heats

He understood that heat
is different from hotness.

http://www.chem.gla.ac.uk/~alanc/dept/black.htm

Using the newly-developed thermometers,
he showed that in thermal equilibrium,
the temperature of all the substances are the same.

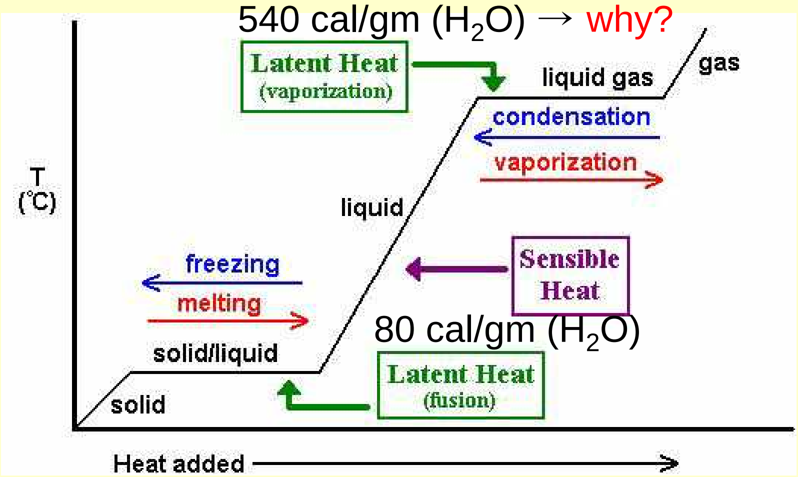
This idea was not easily accepted.
Why?

→ Contradict the ordinary experience of touch:
a piece of metal feels colder than a piece of wood,
even after they have been in contact for a very
long time. (thermal equilibrium)

Why does a piece of metal feel colder?

Black discovered specific heat of substances.

540 cal/gm (H_2O) → why?



80 cal/gm (H_2O)

http://library.thinkquest.org/C006669/data/Chem/thermodynamics/tempheat.html

Caloric Theory of Heat

Served as the basis of thermodynamics.
Is now known to be obsolete

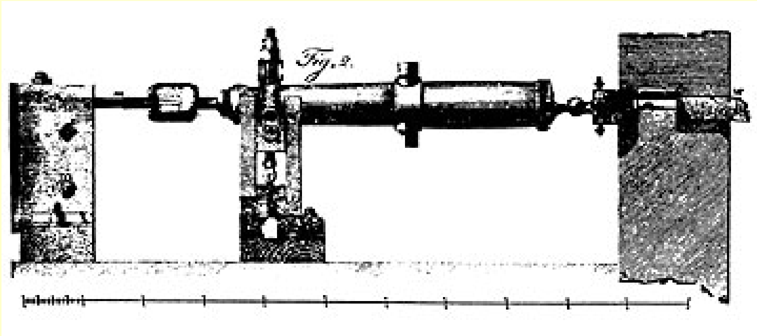
Based on the following assumptions

1. Heat is a fluid that flows from hot to cold substances.
2. Heat has a strong attraction to matter which can hold a lot of heat.
3. Heat is conserved.
4. Sensible heat causes an increase in the temperature of an object when it flows into the object.
5. Latent heat combines with particles in matter (causing substances to melt or boil)
6. Heat is weightless.

The only valid part of the caloric theory is that heat is weightless.
Heat is **NOT** a fluid, as it is **NOT** conserved.

http://library.thinkquest.org/C006669/data/Chem/thermodynamics/tempheat.html

Benjamin Thomson, Count Rumford (1753 - 1815)



“Frictional heat appears to be inexhaustible,
it is given off in a constant flux in all directions
without interruption or intermission and
without any signs of exhaustion.
It is hardly necessary to add that anything
which any insulated body or system of bodies
can furnish without limitation cannot possibly
be a material substance; and it appears to me
to be extremely difficult, if not impossible,
to form any distinct idea of anything being excited
and communicated in these experiments,
except it be motion.”

Count Rumford

In 1803, Lazare Carnot wrote an article on “potential energy”.

In 1784, he wrote his first mathematical work on mechanics, which contains the earliest proof that kinetic energy is lost in the collision of imperfectly elastic bodies.