About Energy

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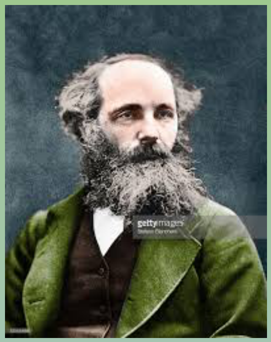
Wind Crest Learners
Academy for Lifelong Learning

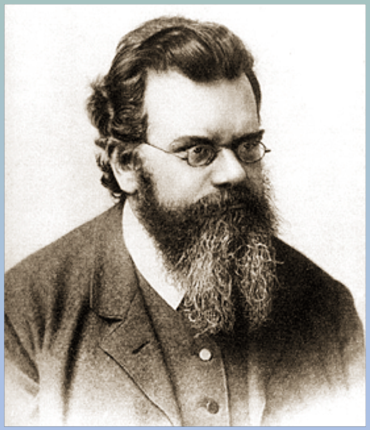
A digression about Energy: connecting the macro to the micro

Maxwell-Boltzmann

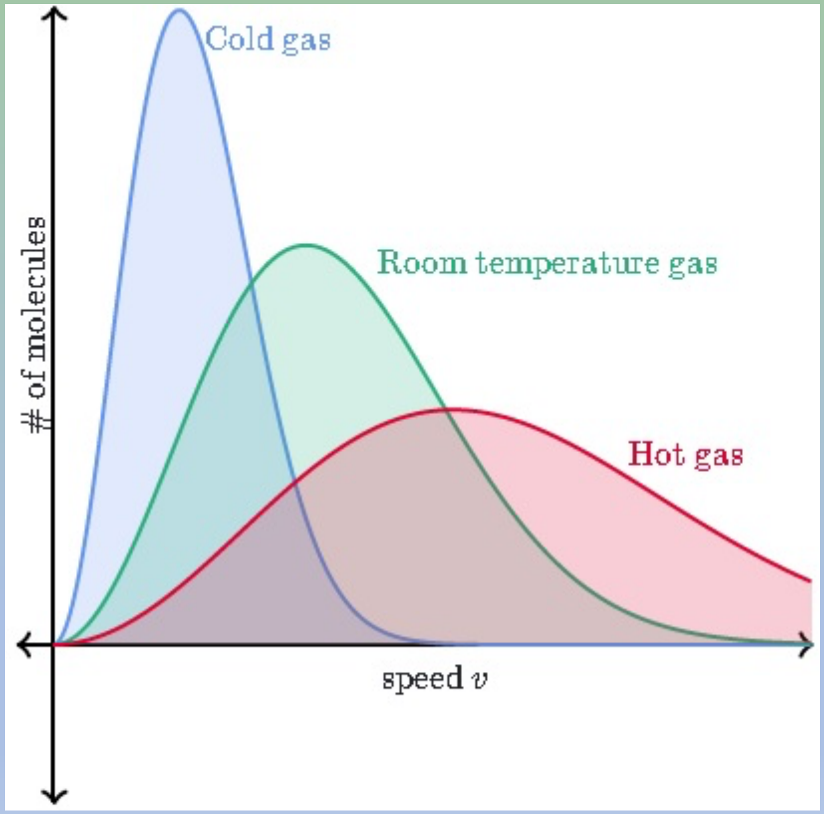
found the distribution of speeds in a gas.



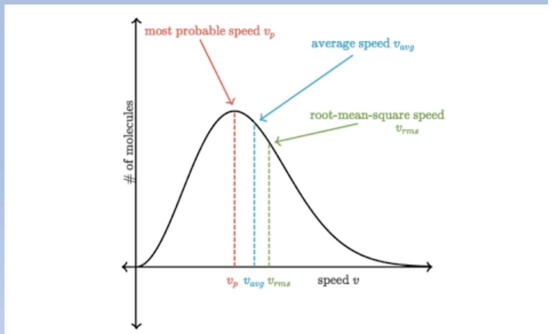
Maxwell



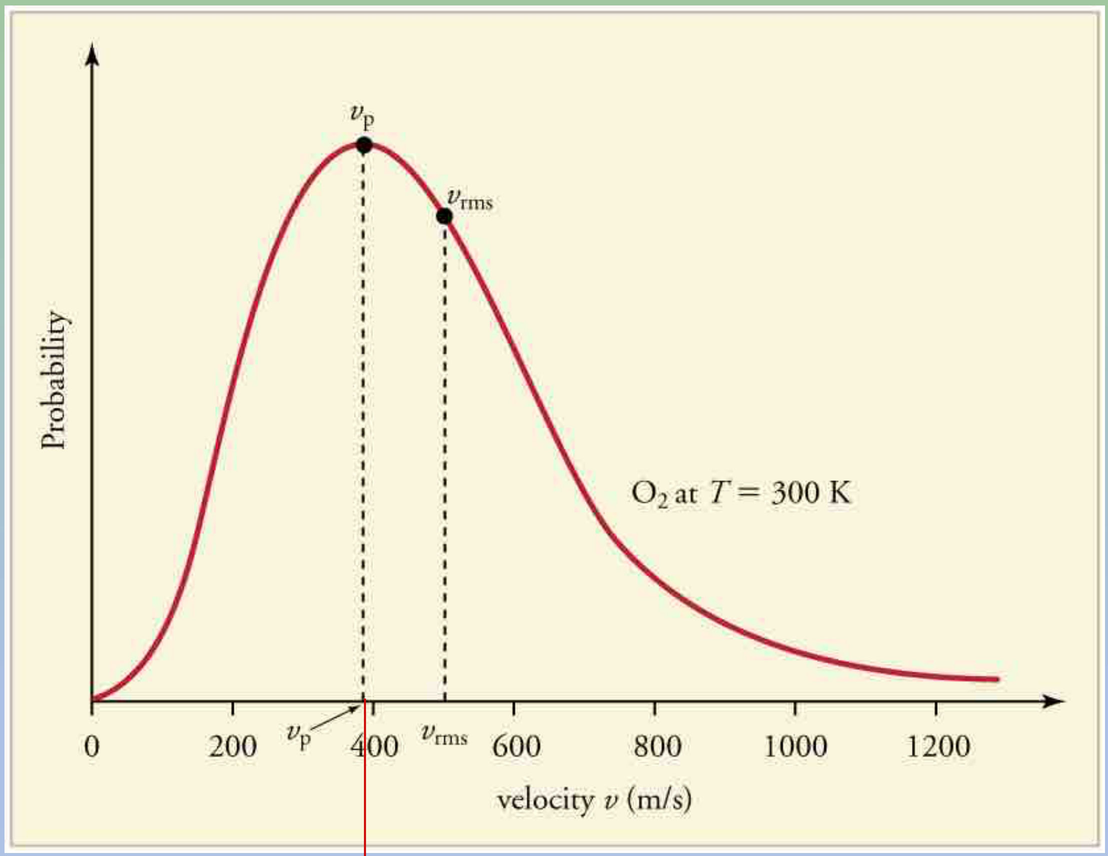
Boltzmann



Molecules move faster in a hotter gas. Hot enough, they are moving fast enough to "burn".



How fast is the air moving?



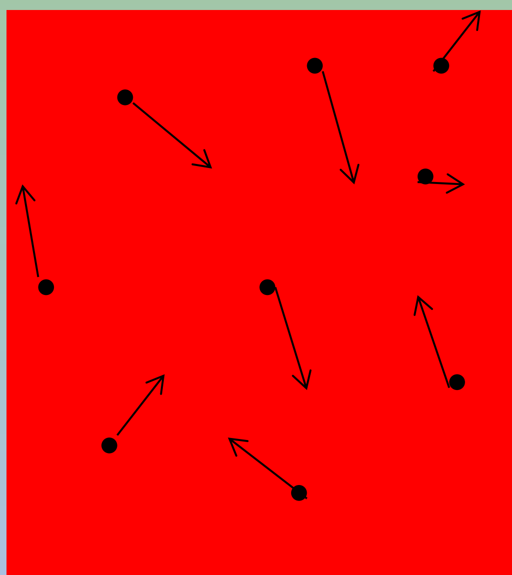
900 miles/hr

A nice outdoor Temperature

300 Kelvin =
26.85 ^oC
80.3 ^oF

Molecular view

Heat, Internal Energy and Temperature



1. Molecules are never at rest: (1000 mi/hr)
2. In air, there are 1.6 x 10^{17} molecules per inch^3
3. 99.9% empty space. But they collide 5 billion times a second
4. The speed increases with temperature

The energy of this motion is the temperature.
At absolute zero the molecules are motionless.

Temperature is a measure of the energy of motion of atoms.

Amedeo Carlo Avogadro
Count of Quaregna and Cerreto
Aug 9, 1776-July 5, 1856

From the macro to the micro

protons + neutrons = nucleons -> Mass

1 kg = 6 x 10^{26} nucleons

Essentially all the mass is in the nucleus

There are minor corrections for the binding energies and masses of the electrons, but we will ignore those here

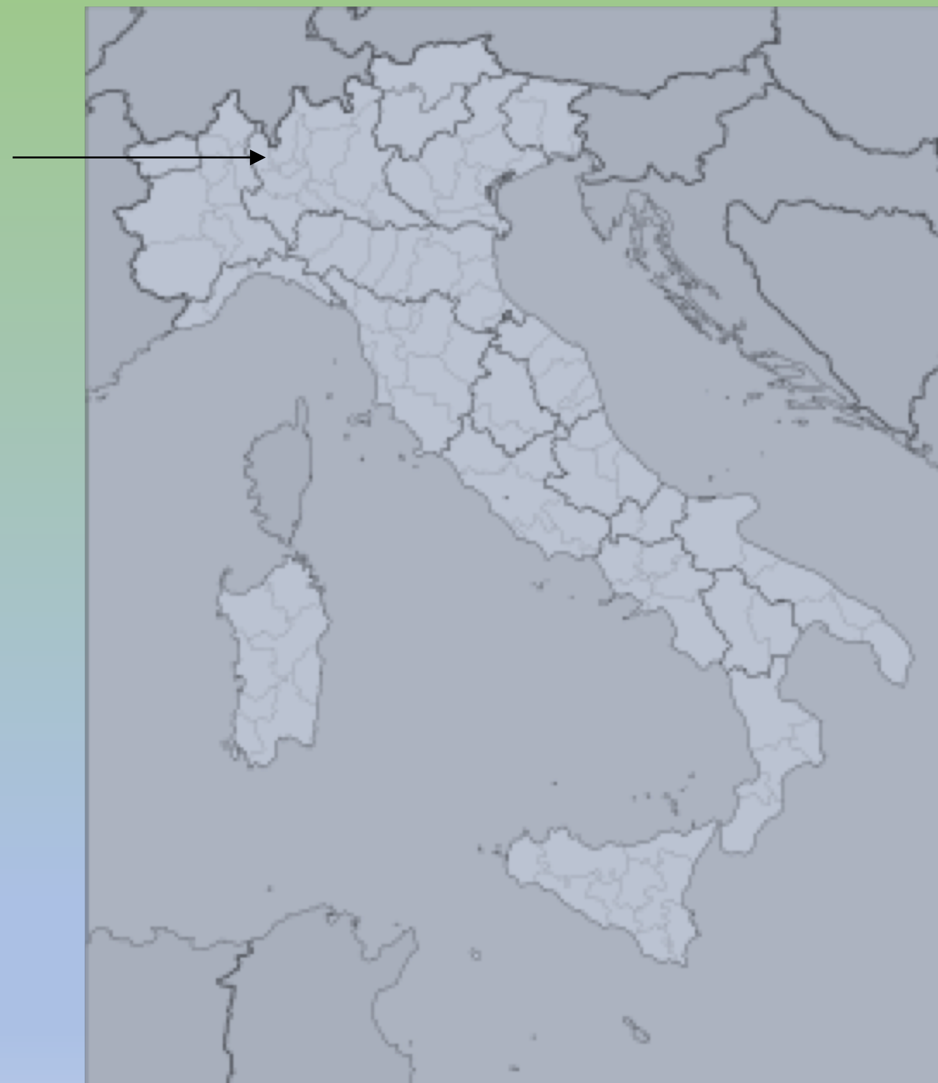
Avogadro's number 1 gm = 6 x 10^{23} nucleons
(aka Loschmidt number)

We simplify and use the number of nucleons, A as the mass:
mass of proton = 1, helium=4, carbon=12 (or 13, stay tuned)

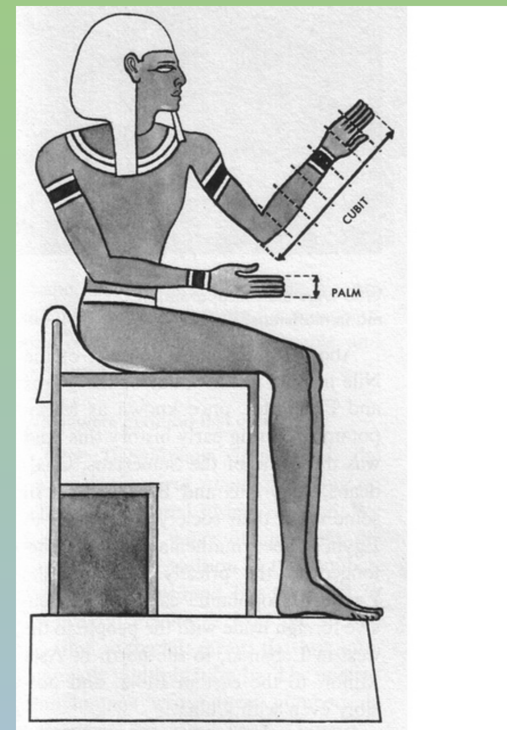
Amedeo Carlo Avogadro

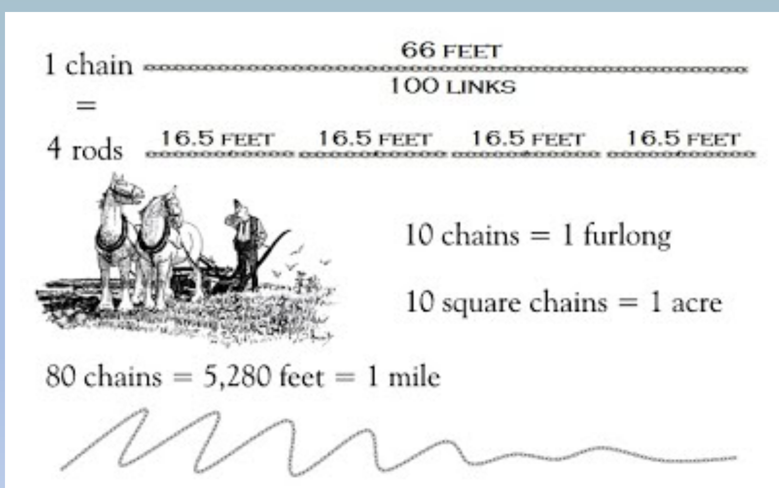
Count of Quaregna and Cerreto
Aug 9, 1776-July 5, 1856

Nondescript place in the foothills of the Italian Alps.



All kinds of units.





My favorite units

- Barn: 10^{-28} m^2, about the cross sectional area of a uranium nucleus.
  - A microbarn, 10^{-6} barns, is sometimes called an "outhouse" by accelerator physicists
- Sydharb; volume of water in the Sydney harbor (harbour)
  - The Grand Canyon has a volume of 10^4 Sydharbs.
- Hiroshima: the energy released by the Hiroshima bomb is about 6×10^{13} J.
- Micromort: A risk unit – 10^{-6} probability of an event causing death.

Use mks units

- m: meters – imagine them as yards
- k: kilograms – a couple of pounds
- s: seconds
- K: Kelvin – temperature from absolute zero
  - 273 K = 0 ^{o}C =32^{o}F (freezing of water)
  - 373 K = 100 ^{o}C = 212^{o}F (boiling of water at sea level)
  - We will deal with temperatures where we can ignore the 273
- Energy: J, Joules
- Power: W, Watt = J/s

Energy units

Everyday energy is in the range of few joules.
  boil a cup of water
  raise an apple and eat it
  walk slowly

100 Joules: Energy of a well-thrown baseball

A human being at rest emits about the same energy as a 100-120 watt lightbulb.

A watt is a Joule/sec. It means expending 1 Joule of energy each second.

Gives new meaning to the phrase
"He's not the brightest bulb in the room."

Big Energies in climate change

- Energy to raise the T of the ocean by 1^{o}C
  - 5.58 x 10^{24} J
- Solar energy hitting Earth each year
  - 3.7 x 10^{24} J

Energy units (eV)

Everyday energy is in the range of 10^{19-20} eV.
boil a cup of water
raise an apple and eat it
walk slowly

$>10^{20}$ eV: Energy of a well-thrown baseball in a single nucleus

1 eV: the energy given to an electron by a 1 volt battery

Much easier to use when we discuss microscopic phenomena or energies of individual particles or photons

Gigajoule (GJ) = 1 *billion* (10^9) joules.

Six gigajoules is about the amount of potential chemical energy in a barrel of oil, when combusted. A barrel is about 42 gallons.

Terajoule (TJ) = 1 *trillion* (10^{12}) joules.

About 63 terajoules were released by the atomic bomb that exploded over Hiroshima. (The national debt is 22 trillion $)

Petajoule (PJ) = 1 *quadrillion* (10^{15}) joules.

210 PJ is equivalent to about 50 megatons of TNT. This is the amount of energy released by Khrushchev's so-called Tsar Bomba, the largest man-made nuclear explosion ever (1961).

Exajoule (EJ) = 1 *quintillion* (10^{18}) joules.

The 2011 Tōhoku earthquake and tsunami in Japan had 1.41 EJ of energy. Energy usage per year in the United States is roughly 94 EJ.

Zettajoule (ZJ) = 1 *sextillion* (10^{21}) joules.

Annual global energy consumption is about 0.5 ZJ, only 5 times larger.

Yottajoule (YJ) = 1 *septillion* (10^{24}) joules.

Approximately the amount of energy required to heat the entire volume of water on Earth by 1 ^{o}Celsius. The solar energy striking Earth is 5.5 YJ/yr.

Energy units: human usage

So how much energy does it take just to keep us all alive for a year?

7.54 x 10^9 humans *120 watts *3600 s/hr *24 hr/day *365 days/yr *1 yr
= 2.8 x 10^{19} joules = 28 ExaJoules = 28 quintillion joules

(a 2000 Cal/day diet is about 10 times this energy; this allows us to think, move around, play tennis, or get fat).

Total annual energy consumption on Earth is 0.26 x 10^{21} joules
= 0.26 ZettaJ = 260 quintillion joules.
So on average, each person is consuming 10 times the energy required to stay alive.

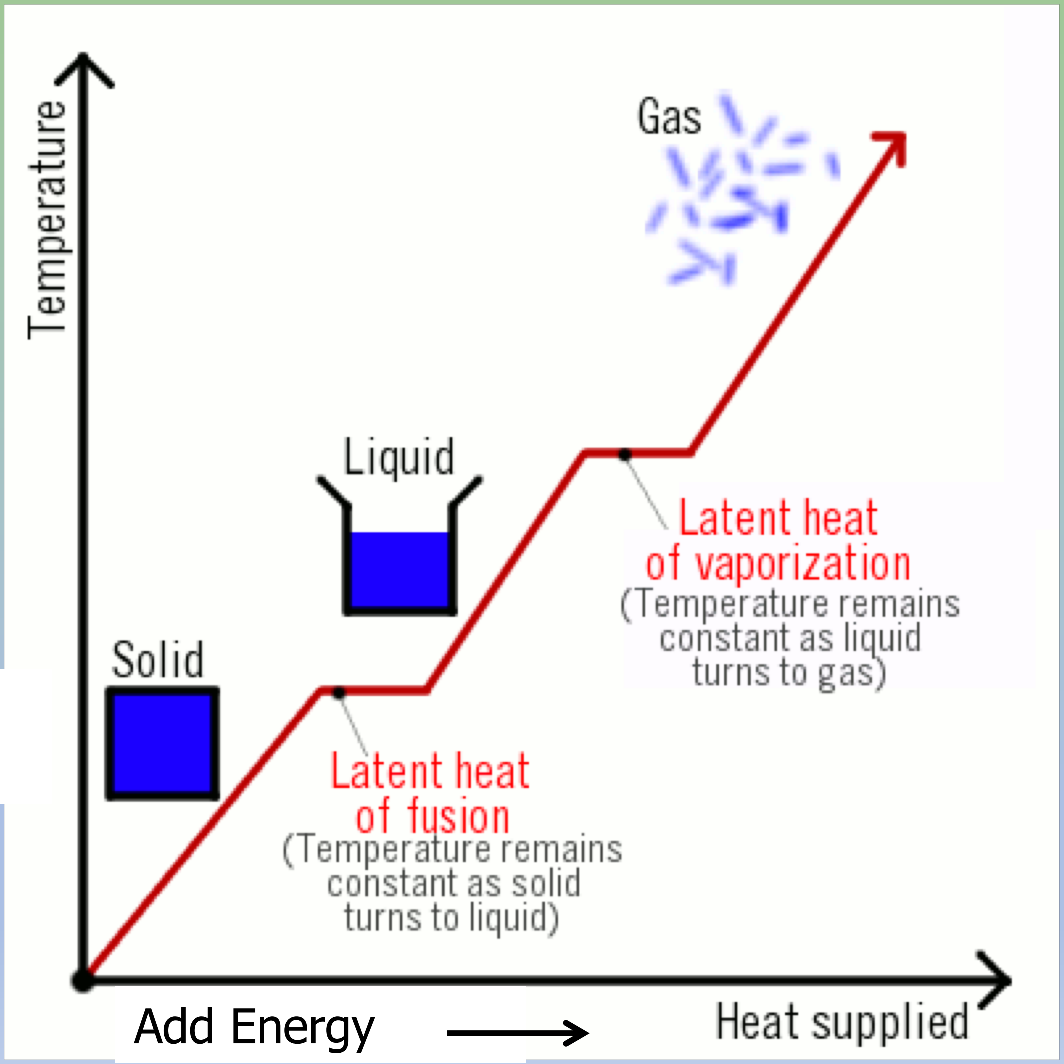
Change in heat content of the Earth since 1975: 2 x 10^{23} joules =
= 0.2 YottaJ = 200 sextillion Joules

Energy for microscopic objects

- Joules work well for macroscopic objects
  - Things with 10^{23} atoms
- We use electron volts (eV)
  - defined as the energy given to an electron by a 1 volt battery
  - for the energies of single particle or photon

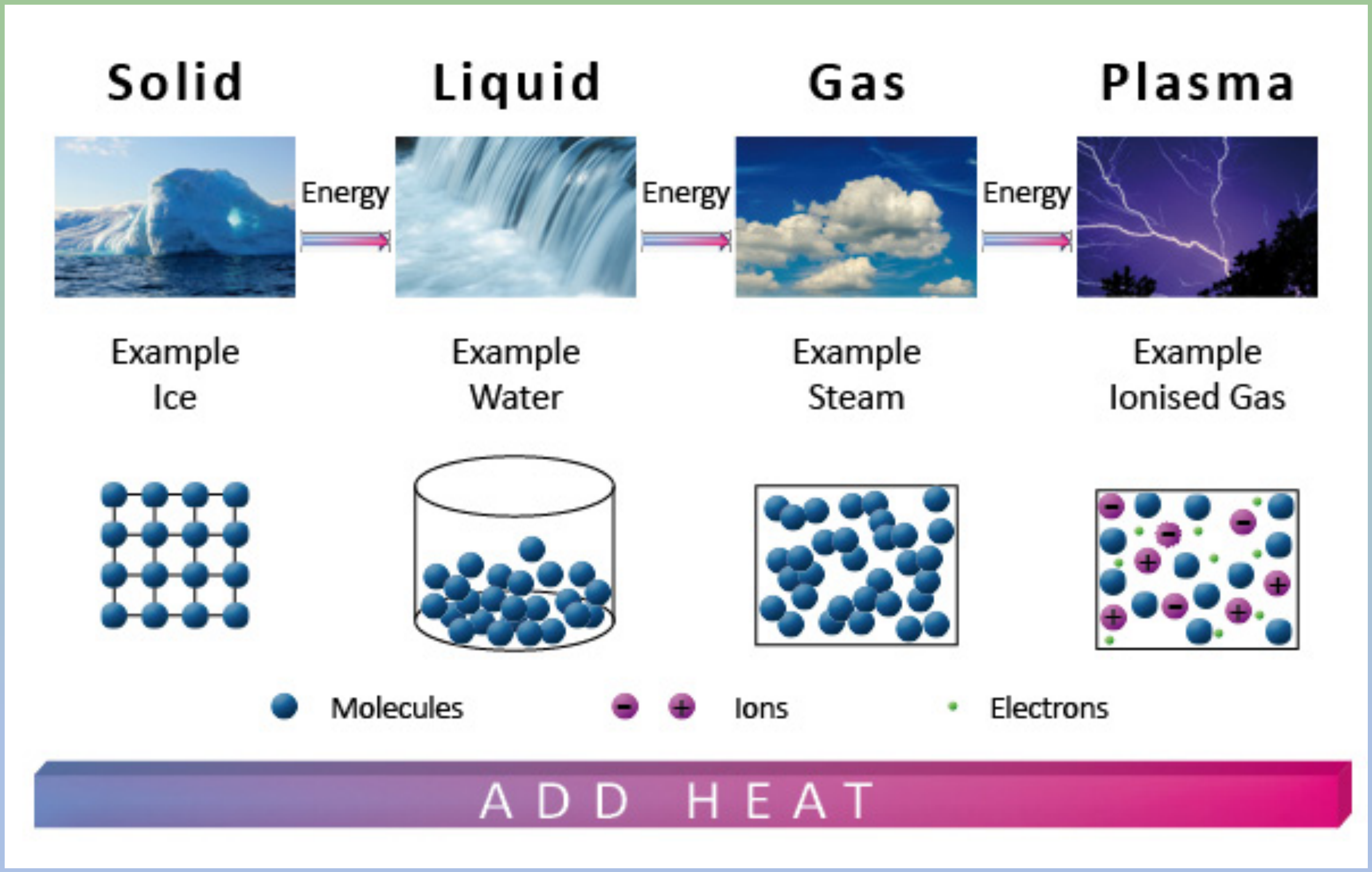
- $1eV = 1.6 \times 10^{-19}$ Joules

Familiar states of matter



Yes, you can have thermal energy in a solid.

4th state of matter



Add more energy, the gas becomes ionized.

Kinetic energy ⇔ Temperature

Kinetic energy (the energy of the moving molecules) =
relates directly to the Temperature of the gas.

No formulas

The constant of proportionality, k_B,
is known as <u>Boltzmann's constant</u>

Kinetic energy ⇔ Temperature

Kinetic energy (the energy of the moving molecules) =
relates directly to the Temperature of the gas.

$$\frac{1}{2}\text{mv}^2 = \frac{3}{2}k_B T$$

The constant of proportionality, k_B,
is known as Boltzmann's constant