


AST1002




Key Concepts for Astronomy

Chapter 4
A Universe of Matter and Energy

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Matter and Energy in Everyday Life

- Matter: Stuff ... can be handled or put in a box; made up of atomic particle (atoms, electrons, protons, neutrons)
- Energy: What makes matter do things
 - Measured in
 - **Calories** (an adult “burns” about 2500 per day)
 - or **joules** (4000 joules = 1 Calorie)

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Matter and Energy in Everyday Life

- Energy: What makes matter do things
 - Kinetic energy: energy of motion
 - Potential energy: stored energy
 - Gravitational potential energy
 - Chemical potential energy
 - Electrical potential energy
 - Radiative energy
- Energy is frequently converted from one form to another

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A Scientific View of Energy


- Kinetic energy
 - $E = \frac{1}{2} mv^2$
if $m = \text{mass (kilograms)}$,
 $v = \text{velocity (meters per second)}$,

Then E is in joules



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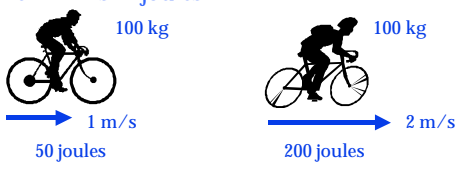
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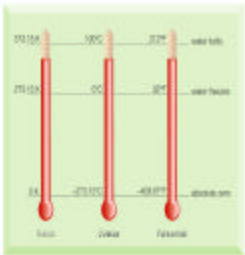


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A Scientific View of Energy

- Temperature scales
 - Fahrenheit
 - Celsius
 - Kelvin

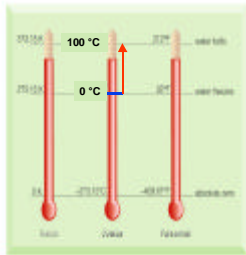


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A Scientific View of Energy

- Temperature scales
 - Fahrenheit
 - **Celsius**
 - Kelvin
- Defined by
 - Zero point
 - **Scale**

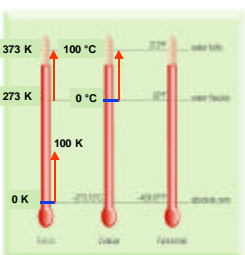


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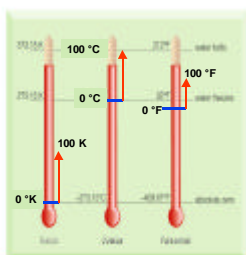


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A Scientific View of Energy

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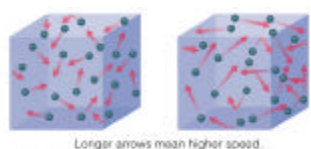


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A Scientific View of Energy

- Temperature
 - The average kinetic energy of the atoms in the material or gas
 - Related to the average speed ($v \propto \sqrt{T}$)



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A Scientific View of Energy

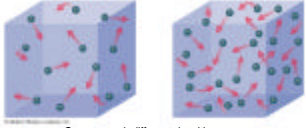
- Temperature
 - The average kinetic energy of the atoms in the material or gas
 - Related to the average speed ($v \propto \sqrt{T}$)
- Why use the Kelvin temperature scale?
 - Hint ... how does \sqrt{T} behave at cold temperatures? At what T should $v=0$ (all motion stopped)?

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A Scientific View of Energy

- Heat
 - Related to the total thermal energy so it depends on both
 - Temperature and
 - Density (number of atoms)





Same speed, different densities

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A Scientific View of Energy

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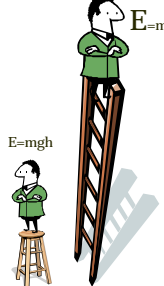
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A Scientific View of Energy

- Potential Energy
- Gravitational Energy

The amount of gravitational potential energy depends on the mass, the strength of gravity, and the height $E=mgh$




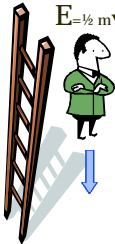
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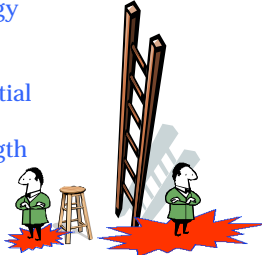
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A Scientific View of Energy

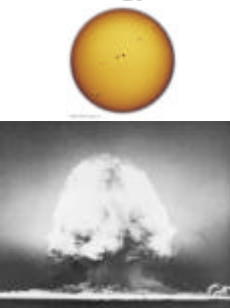
- Potential Energy
- Mass-energy

$$E=mc^2$$

E=energy (joules)
 m=mass (kilograms)
 c=constant (speed of light; 3×10^8 m/s)

so 1 gram contains 9×10^{13} joules (225 billion Calories)

- Conservation of Energy



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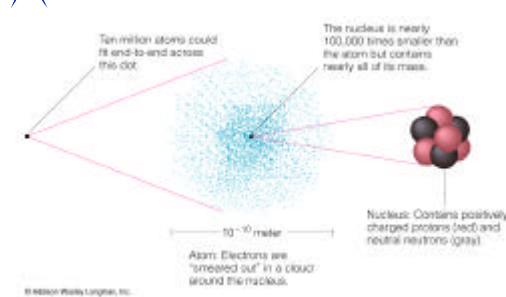
The Material World

- Solid
- Liquid
- Gas
- Molecules
- Atoms
- Electrons
- Protons
- Neutrons

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The Material World



Ten million atoms could fit end-to-end across this dot.

The nucleus is nearly 100,000 times smaller than the atom but contains nearly all of its mass.

Nucleus: Contains positively charged protons (red) and neutral neutrons (gray).

Atom: Electrons are "smeared out" in a cloud around the nucleus.

10⁻¹⁰ meter

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The Material World

atomic number = number of protons
 atomic weight = number of protons + neutrons

Hydrogen (1H)	Helium (4He)	Carbon (12C)
atomic number = 1 atomic weight = 1 (1 electron)	atomic number = 2 atomic weight = 4 (2 electrons)	atomic number = 6 atomic weight = 12 (6 electrons)

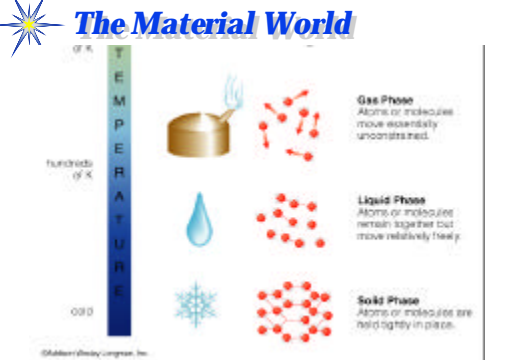
The number of electrons in a neutral atom equals its atomic number.

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The Material World



TEMPERATURE

1000
 hundreds of K
 000

Gas Phase
 Atoms or molecules move essentially unconstrained.

Liquid Phase
 Atoms or molecules remain together but move relatively freely.

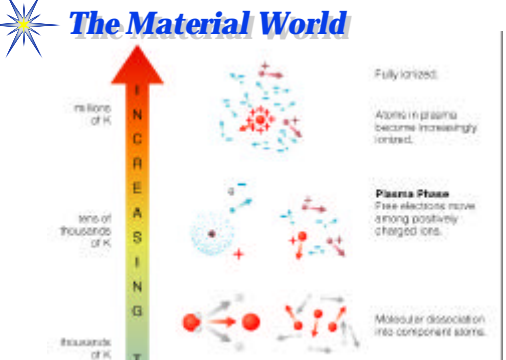
Solid Phase
 Atoms or molecules are held tightly in place.

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The Material World



millions of K
 hundreds of K
 thousands of K

IONIZATION

Fully ionized.
 Atoms in plasma become increasingly ionized.

Plasma Phase
 Free electrons move among positively charged ions.

Molecular dissociation into component atoms.


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The Material World

Atoms can be ionized multiple times if they have more than one electron: higher T means more ionization



Fully ionized:
Atomic plasma become increasingly ionized.

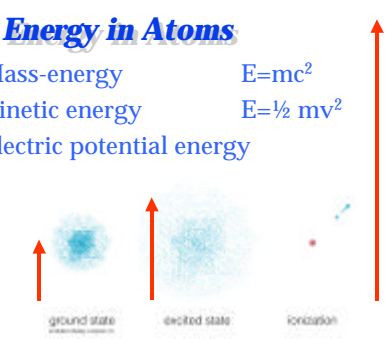
Atom	# protons	# electrons	
Hydrogen	1	1	H ⁰ , H ⁺
Helium	2	2	He ⁰ , He ⁺ , He ⁺²
Oxygen	8	8	O ⁰ , O ⁺ ... O ⁺⁸
Iron	26	26	Fe ⁰ , Fe ⁺ ... Fe ⁺²⁶

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Energy in Atoms

- Mass-energy $E=mc^2$
- Kinetic energy $E=\frac{1}{2}mv^2$
- Electric potential energy



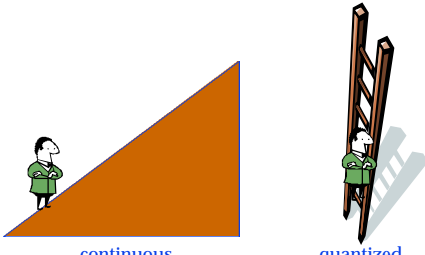
ground state excited state ionization

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Energy in Atoms

- Electric potential energy is *quantized*



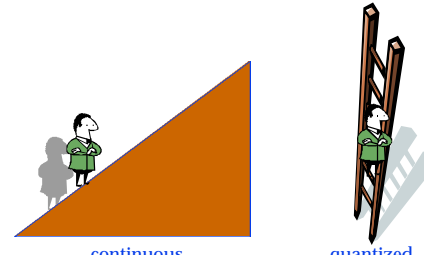
continuous quantized

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Energy in Atoms

- Electric potential energy is *quantized*



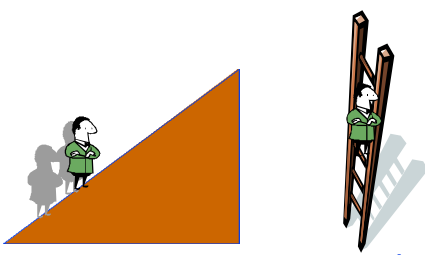
continuous quantized

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Energy in Atoms

- Electric potential energy is *quantized*



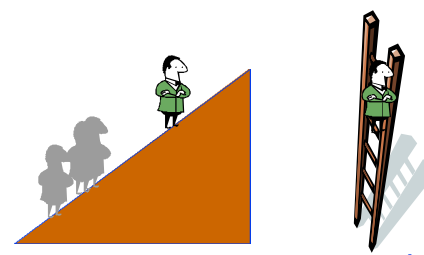
continuous quantized

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Energy in Atoms

- Electric potential energy is *quantized*



continuous quantized

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Energy in Atoms

- Electric potential energy is *quantized*

continuous quantized

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Energy in Atoms

- 1 electron-volt (eV) = 1.6×10^{-19} joule

ionization level	13.6 eV
level 4	12.6 eV
level 3	12.1 eV
level 2	10.2 eV
level 1 (ground state)	0 eV

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Energy in Atoms

- Energy can be absorbed

in a collision
or from light

ionization level	13.6 eV
level 4	12.6 eV
level 3	12.1 eV
level 2	10.2 eV
level 1 (ground state)	0 eV

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Energy in Atoms

- Energy can be given off as well

as emitted light
or in a collision

ionization level	13.6 eV
level 4	12.6 eV
level 3	12.1 eV
level 2	10.2 eV
level 1 (ground state)	0 eV

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Questions and/or Comments?

Let me know at oliver@astro.ufl.edu

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