4. A Universe of Matter and Energy

"The eternal mystery of the world is its comprehensibility. The fact that it is comprehensible is a miracle."

Albert Einstein (1879 – 1955)
Physicist

4.1 Matter and Energy in Everyday Life

What are Matter and Energy?

matter – is material such as rocks, water, air.

energy – is what makes matter move!

Energy is measured in many different units.

The metric unit of energy used by scientists is:

Joule

4,184 joules = 1 calorie

Table 4.1 Energy Comparisons

Item	Energy (joules)
Average daytime solar energy striking Earth, per m^2 per second	1.3×10^3
Energy released by metabolism of one average candy bar	1×10^6
Energy needed for 1 hour of walking (adult)	1×10^6
Kinetic energy of average car traveling at 60 mi/hr	1×10^6
Daily energy needs of average adult	1×10^7
Energy released by burning 1 liter of oil	1.2×10^6
Energy released by fission of 1 kg of uranium-235	5.6×10^{13}
Energy released by fusion of hydrogen in 1 liter of water	7×10^{13}
Energy released by 1-megaton H-bomb	5×10^{15}
Energy released by major earthquake (magnitude 8.0)	2.5×10^{16}
U.S. annual energy consumption	10^{20}
Annual energy generation from the Sun	10^{34}
Energy released by supernova (explosion of a star)	10^{44}–10^{46}

Three Basic Types of Energy

- **kinetic**
  - energy of motion
- **potential**
  - stored energy
- **radiative**
  - energy transported by light

Energy can change from one form to another.

4.2 A Scientific View of Energy

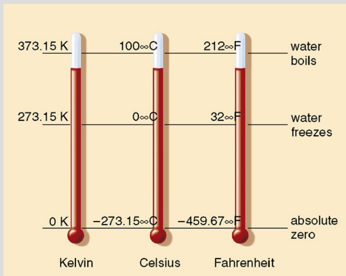
Kinetic Energy

- Amount of kinetic energy of a moving object
  - = $1/2 \, mv^2$

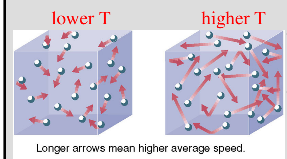
[if mass (m) is in kg & velocity (v) is in m/s, energy is in joules]

- On the microscopic level
  - the average kinetic energy of the particles within a substance is called the **temperature**.
  - it is dominated by the velocities of the particles.

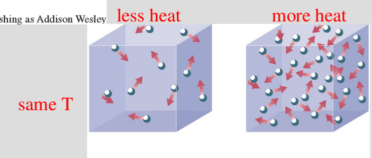
Temperature Scales



Temperature vs. Heat

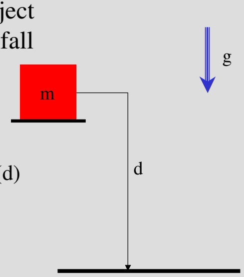


- Temperature is the <u>average</u> kinetic energy.
- Heat (thermal energy) is the <u>total</u> kinetic energy.



Potential Energy

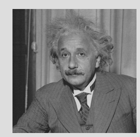
- *gravitational* potential energy is the energy which an object stores due to its ability to fall
- It depends on:
  - the object's mass (m)
  - the strength of gravity (g)
  - the distance which it falls (d)



Potential Energy

- energy is stored in matter itself
- this *mass-energy* is what would be released if an amount of mass, m, were converted into energy

$$E = mc^2$$



[c = 3 x 10^8 m/s is the speed of light; m is in kg, then E is in joules]

Conservation of Energy

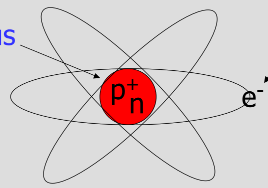
- Energy can be neither created nor destroyed.
- It merely changes its form or is exchanged between objects.
- This principle (or *law*) is fundamental to science.
- The total energy content of the Universe was determined in the Big Bang and remains the same today.

4.3 The Material World

Atom

nucleus

electron

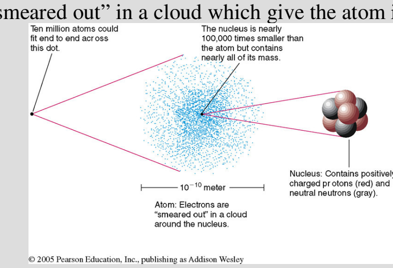


proton

neutron

The “size” of an Atom

- Although it is the smallest part of the atom, most of the atom’s mass is contained in the nucleus.
- The electrons do not “orbit” the nucleus; they are “smeared out” in a cloud which give the atom its size.



Periodic Table of the Elements

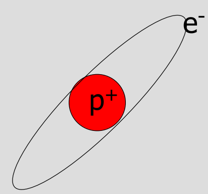
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57–71 La–Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89–103 Ac–Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt									

Lanthanoids	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinoids	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

atomic number = #protons

atomic mass no. = #protons + #neutrons

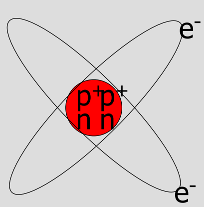
Hydrogen



atomic number = 1

atomic mass number = 1

Helium



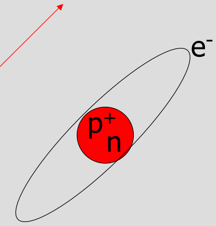
atomic number = 2

atomic mass number = 4

~~Hydrogen~~

Deuterium

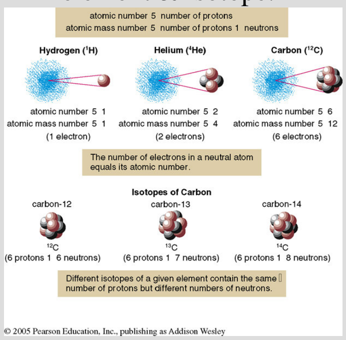
isotope



atomic number = 1

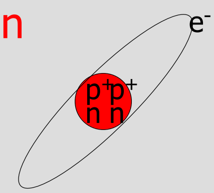
atomic mass number = 2

The particles in the nucleus determine the element & isotope.



What if an electron is missing?

ion

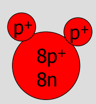


atomic number = 2
atomic mass number = 4

He^{+1}

What if two or more atoms combine to form a particle?

molecule

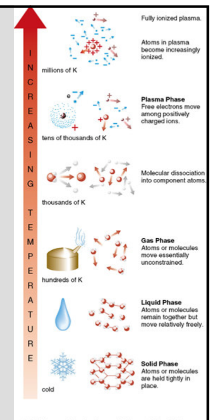


H_2O (water)

Phases of Matter

- the phases
  - solid
  - liquid
  - gas
  - plasma

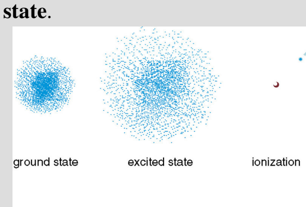
  depend on how tightly bound the atoms and/or molecules are
- As temperature increases, these bonds are loosened:



4.4 Energy in Atoms

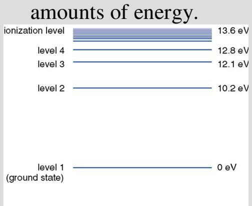
Electron Orbits

- Electrons can gain or lose energy while they orbit the nucleus.
- When electrons have the lowest energy possible, we say the atom is in the **ground state**.
- When electrons have more energy than this, we say the atom is in an **excited state**.
- When electrons gain enough energy to escape the nucleus, we say the atom is **ionized**.



Electron Energy Levels

- But, electrons can not have just <u>any</u> energy while orbiting the nucleus.
- Only certain energy values are allowed.
- Electrons may only gain or lose certain specific amounts of energy.



- Each element (atom and ion) has its own distinctive set or pattern of energy levels.
- This diagram depicts the energy levels of Hydrogen.

What have we learned?

- What is matter? What is energy?
  - Matter is material. Energy is what makes matter move.
- What is a joule?
  - A joule is the standard unit of energy. It is used to quantify and compare energies.
- What are the three basic categories of energy?
  - Kinetic energy is energy of motion. Potential energy is stored energy that can be released later. Radiative energy is energy carried by light.

What have we learned?

- What is temperature, and how is it different from heat?
  - Temperature is a measure of the average kinetic energy of the many individual atoms or molecules and a substance. At a particular temperature, a denser substance contains more thermal energy (heat).
- What is gravitational potential energy?
  - It is energy stored because of an object's ability to fall from its current position. The amount of an object's gravitational potential energy depends on its mass, the strength of gravity, and how far it could fall.

What have we learned?

- Explain the formula $E = mc^2$.
  - It describes the potential energy of mass itself. E is the energy stored in a piece of matter of mass m, and c is the speed of light.
- Why is the law of conservation of energy so important?
  - It tells us that energy can be neither created nor destroyed and instead can only be exchanged between objects or transformed from one form to another. We can, therefore, understand many processes in the Universe by tracking the path of energy.

What have we learned?

- What is the basic structure of an atom?
  - An atom consists of a tiny nucleus made of protons and neutrons surrounded by a "smeared out" cloud of electrons that give the atom its size.
- Distinguish between atomic number and atomic mass number.
  - Atomic number is the number of protons in an atom's nucleus. Atomic mass number is the sum of the number of protons and neutrons.

What have we learned?

- How do phases of matter change with increasing temperature?
  - Most substances are solid at low temperature. As temperature rises, the substance may melt into liquid and then evaporate into gas. As temperature rises further, molecules (if any) will dissociate and atoms will be ionized to make a plasma.

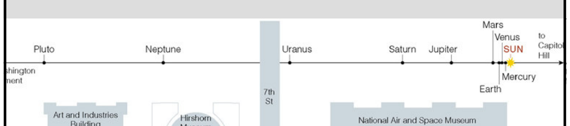
What have we learned?

- What is surprising about energy in atoms?
  - Electrons can have only particular amounts of electrical potential energy, not amounts in between. Electrons can jump between the allowed energy levels only by gaining or losing the precise amounts of energy separating levels.
- How do energy levels differ from one chemical element to another?
  - Every chemical element has its own unique set of energy levels.

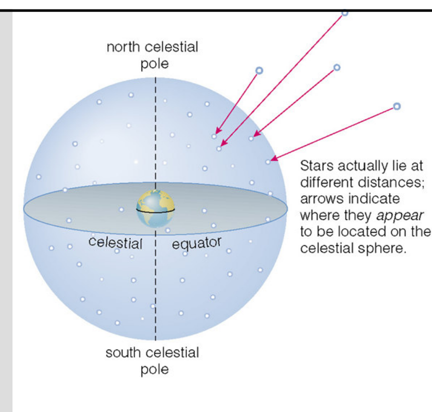
Review for test

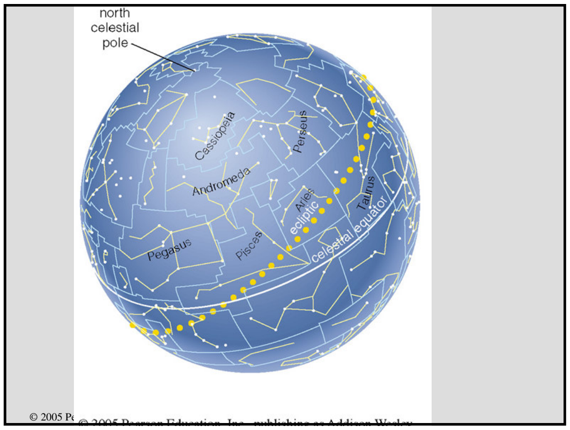
- Take conceptual quizzes (don't need to submit)
- Look at the important diagrams

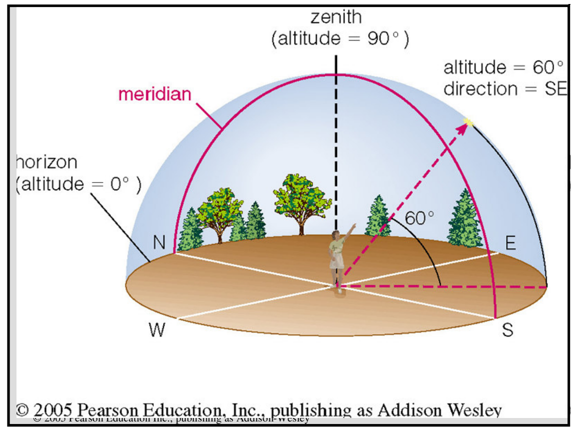
Do you appreciate range of scales?
Ordering of sizes?

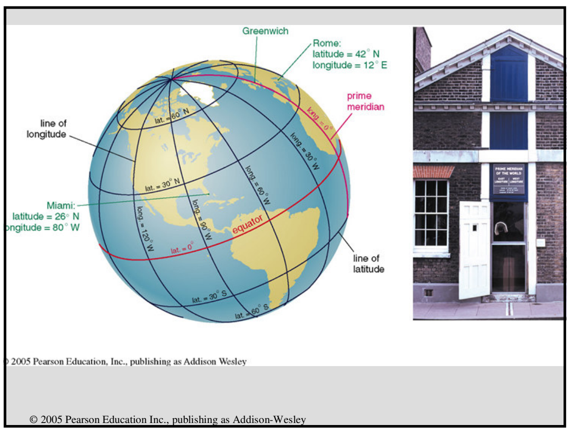


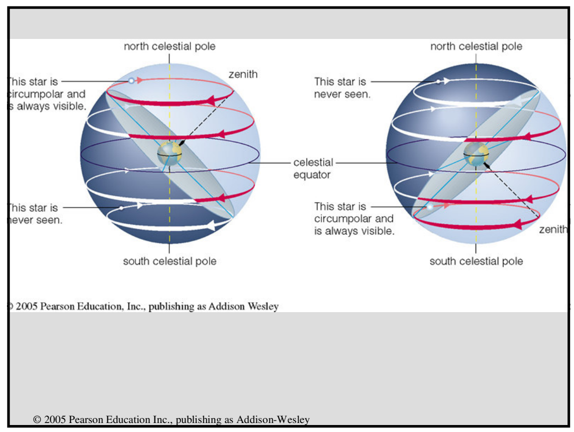
oyage scale model solar system represents sizes and distances in our solar system at one ten-billionth of actual values (see Figure 1.7). The strip along the side of the page shows the sizes of the Sun and planets s scale, and the map above shows their locations in the Voyage model on the National Mall in Washington. The entire Sun is about the size of a large grapefruit on this scale.

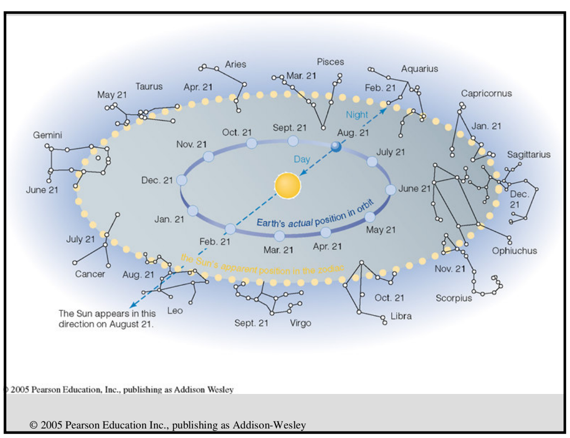


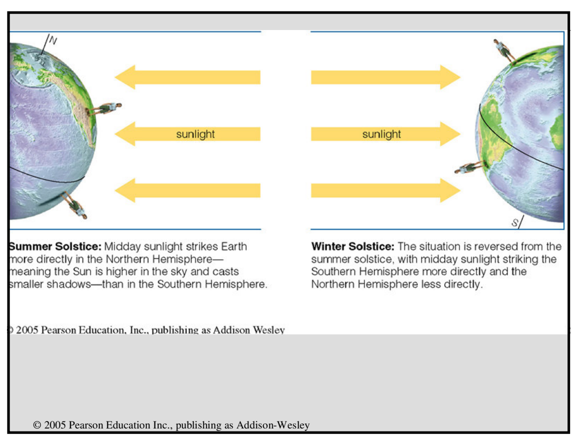

north
celestial
pole
Cassiopeia
Perseus
Andromeda
Aries
ecliptic
Taurus
celestial equator
Pegasus
Pisces

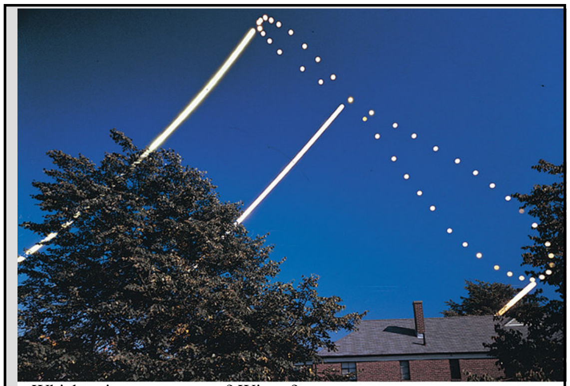

zenith
(altitude = 90°)
altitude = 60°
direction = SE
meridian
horizon
(altitude = 0°)
60°
N
E
W
S


Greenwich
Rome:
latitude = 42° N
longitude = 12° E
prime
meridian
line of
longitude
Miami:
latitude = 26° N
longitude = 80° W
equator
line of
latitude

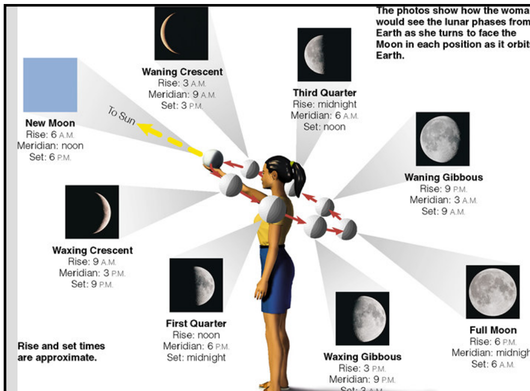

north celestial pole
zenith
This star is
circumpolar and
is always visible.
This star is
never seen.
celestial
equator
This star is
never seen.
This star is
circumpolar and
is always visible.
south celestial pole
north celestial pole
zenith
south celestial pole


Aries
Pisces
Aquarius
Capricornus
Taurus
May 21
Apr. 21
Mar. 21
Feb. 21
Jan. 21
Gemini
Night
Sagittarius
Sept. 21
Aug. 21
Oct. 21
Nov. 21
July 21
Day
Dec. 21
June 21
Dec. 21
June 21
Jan. 21
Earth's actual position in orbit
May 21
July 21
Feb. 21
Mar. 21
Apr. 21
Ophiuchus
Cancer
Aug. 21
Nov. 21
Oct. 21
Scorpius
The Sun appears in this
direction on August 21.
Leo
Sept. 21
Virgo
Libra

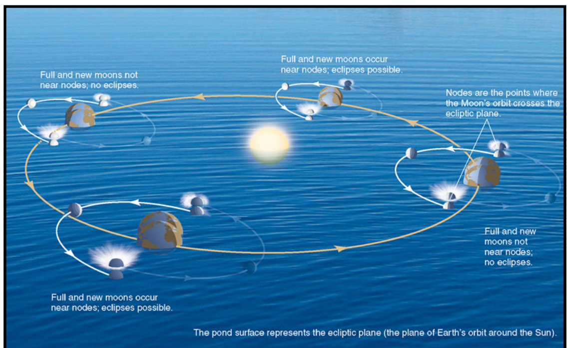

N
sunlight
sunlight
S
Summer Solstice: Midday sunlight strikes Earth
more directly in the Northern Hemisphere—
meaning the Sun is higher in the sky and casts
smaller shadows—than in the Southern Hemisphere.
Winter Solstice: The situation is reversed from the
summer solstice, with midday sunlight striking the
Southern Hemisphere more directly and the
Northern Hemisphere less directly.

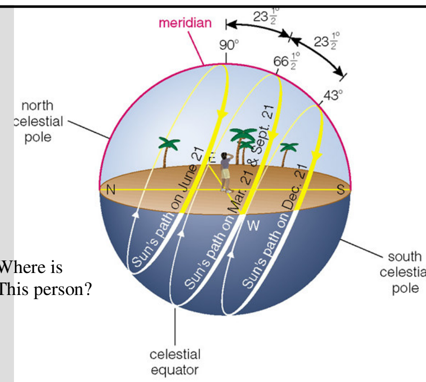


Which points are summer? Winter?

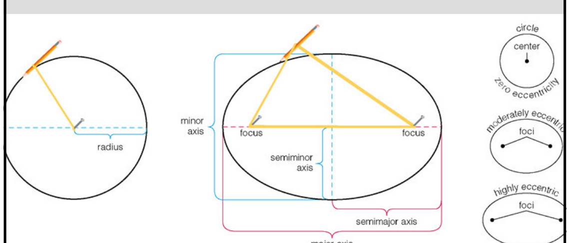


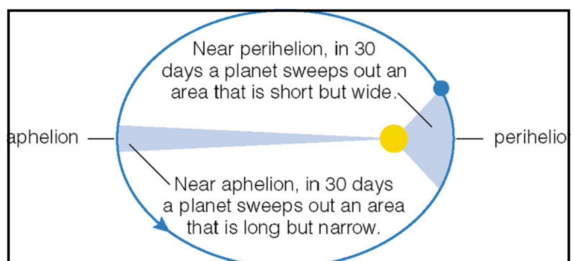
Do you have to memorize or can you reason out Meridian times?



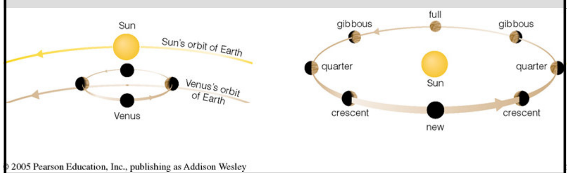


Where is
This person?





The areas swept out in 30-day periods are all equal.



Whose model is on the left?
What's the significance of the one on the right?

What does the symbol ^{3}He represent?

1. An isotope of Hydrogen containing one proton and two neutrons.
2. An isotope of Helium containing one proton and two neutrons.
3. An isotope of Helium containing two protons and one neutron.
4. A charged Helium ion, containing three protons and two electrons.
5. Three Helium atoms.

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When I drive my car at 30 miles per hour, it has more kinetic energy than it does at 10 miles per hour.

1. Yes, it has three times as much kinetic energy.
2. Yes, it has nine times as much kinetic energy.
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If you put an ice cube outside the Space Station, it would take a very long time to melt, even though the temperature in Earth orbit is several thousand degrees Celsius.

1. Yes, even though the temperature in orbit is quite high, the density is so low that there is little opportunity for the ice cube to absorb thermal energy from other particles.
2. Yes, the vacuum of space prevents the ice cube from sublimating quickly.
3. No, the vacuum of space would speed up the melting and evaporation process.
4. No, the ice cube will readily melt at such high temperatures.
5. No, the low gravity in orbit actually means the ice cube would melt more rapidly than at the same temperature on the Earth's surface.

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Two ions, each carrying a positive charge of +1, will attract each other electrically.

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2. Yes, but the electron cloud around each ion will prevent them from getting too close.
3. No, they will repel each other.
4. No, the electron cloud around each ion will neutralize the charge around them.
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