Astro 350

Lecture 9

Sept. 12, 2011

Announcements:

- Discussion Question 3 due Wednesday
- HW3 available, due in 1 week

Please take and test-drive a diffraction grating slide

Last time: light

Clever measurements of light can reveal

- ▷ temperature via Wien's Law
- ▷ speed via Doppler effect

Today: energy, matter, & light

Composition

recall: matter made of *atoms*
which come in a fixed set of *elements*
and different elements combine/react differently $\Rightarrow$ chemistry
ex: water = H_2O = H-O-H

so: the question of "what is object X made of?"
= what is the "[chemical] composition" of X?
at deepest (=microscopic) level really asks:
▷ what kinds of elements?
▷ which are most, least numerous?

Examples
Earth: about 50% oxygen, 30% silicon, only 0.1% hydrogen
Sun, Jupiter: about 70% hydrogen, 28% helium, 2% other="metals"
`www: solar system composition pie chart`

Energy

every closed system has a *number*, the **energy**, which:

- is related to the forces in the system
- roughly corresponds to the ability of the system to do work–i.e., to change speeds, move with or against forces, or to undergo internal transformations
  Cosmologist L. Cable Guy: Energy is ability to "git-r-done"

★ key feature: in *closed system*, total energy doesn't change:
conservation of energy

more abstract (and more general) idea than forces
useful due to conservation

Energy: Two Crucial Cases

Motion: moving object with mass m, speed v carries **kinetic energy**

$$KE = \frac{1}{2} m v^2 \tag{1}$$

Q: when is $KE = 0$? large?

Gravity: object of mass m, a distance R from mass M has gravitational potential energy

$$PE = -\frac{GMm}{R} \tag{2}$$

Q: where is PE=0,i.e., at what R? what happens when $R = 0$?

Q: how does PE at ground compare to PE 1 meter high?

Q: dropped object to floor: PE? KE?

Q: bouncing ball: what happens to KE, PE, total E?

Q: why called “potential” energy?

Forces & Energy

Forces $\neq$ energy *Q: what are some differences?*
but forces always have associated energy
for example: can "store" energy due to position
in force field (e.g., gravity) $\Rightarrow$ potential energy

examples:

force	**energy**
gravity	gravitational potential energy
electricity	electrical potential energy
gas pressure	"compression energy"
attractive forces in atoms (chemical forces)	bonds in atoms (chemical energy)
forces in atomic nuclei	nuclear energy

iClicker Poll: Light and Atoms

Experiment: tube with gas under high voltage
$\rightarrow$ high-energy electrons accelerated, collide with gas atoms
atoms receive energy from collisions, emit light

Vote your conscience!
What will spectrum of tube look like?

A continuous: all visible colors = all λs

B bands of colors = λs in only some ranges

C only a few *single* colors = a few individual λ

demo: compare spectrum for different elements
Q: why is this incredibly useful?

The Quantum Atom

at small distances (size of atoms) Newton's laws *fail*!
atoms, light obey different rules: **quantum mechanics**

electron orbits
nucleus + e: like solar system?
No! QM → e not like planet
in atom, acts like wave !?!
▷ *most* orbits *forbidden*!
▷ only special orbit distances allowed → "quantized" in steps

allowed orbits → **energy levels**
lowest energy → stable orbit, closest to nucleus
"ground state"

Photons

just as matter (like e) can sometimes act like waves
light can sometimes act like particles...

on small lengthscales or low intensities
light acts like *particle*: "**photon**," symbol γ

discrete "lump" or "packet" of energy
different colors $\leftrightarrow$ different energies
smaller $\lambda \rightarrow$ higher E:

$$E_{\text{photon}} \propto \frac{1}{\lambda} \tag{3}$$

∞

`www: EM spectrum as spectrum of photon energies`

Light-Atom Interactions

If light hits atom **and** photon energy = atom energy level

1. atom absorbs photon
2. e jumps to higher level
3. atom in “excited” state

but excited = unstable

after time,

1. e jumps back to ground state
2. emits photon whose energy = excited − ground *difference*

Atoms absorb/emit light

atom structure sets energies, and $\lambda \propto 1/E$

...which is different for different atoms

so energy level spacings different for different atoms

light spectrum gives atom "fingerprint" or "barcode"

spectrum $\rightarrow$ composition

Measuring the Composition of the Cosmos

Example: The Sun

Sun, stars hotter, denser in center cooler, less dense at surface
so: sunlight/starlight shows *Q: what kind of spectrum?*
`www: Sun spectrum`
amount absorbed in each line → amount of atoms
→ **composition** of Sun; works for other stars too!

Example: Foreground of Quasars

Quasar: really–monstrous supermassive black hole
devouring gas and ejecting luminous jet
for our purposes today: a lightbulb/cosmic beacon
→ light from hot material across universe passes thru
intervening gas (if any) to get to us

Q: is there much intervening gas? (guess!)
Q: if so, what elements might be prominent?
Q: should it give emission or absorption features?