Astro 350

Lecture 8

Sept. 9, 2011

Announcements:

- HW2 due now
- Discussion Question 3 due next Wednesday
- HW1 returned today
- HW3 available, due in 1 week

Last time: light = electromagnetic radiation

Q: why is light "electromagnetic"?

Q: why is light "radiation"

Q: directly measurable properties of light?

Visible Light Revisited

Recall: visible light is only tiny part of
full electromagnetic spectrum

	radio	infrared	visible	ultraviolet	X-ray	γ-ray
λ [m]	$> 10^{-3}$	$\sim 10^{-5}$	$(4-7) \times 10^{-7}$ m	$\sim 10^{-9}$	$\sim 10^{-11}$	$\sim 10^{-12}$

Visible Light

- wavelengths small on human scale ($< 10^{-3}$mm)
  but much smaller λ light exists!
- prisms & rainbows: sort light by λ
- longest visible λ: red light
- shortest visible λ: blue light
- order, in decreasing λ
  red, orange, yellow, green, blue, indigo, violet
  think of Mr. "Roy G. Biv"

Heat and Light

hot objects **glow**

temperature–radiation connection

glow due to temperature: **thermal radiation**

color & brightness of thermal glow = spectrum & intensity:
depends on temperature T

- hotter $\rightarrow$ brighter
- color change: hotter $\rightarrow$ bluer
  larger T $\rightarrow$ *smaller* λ_{peak}!

Blackbody Spectrum

useful* to define an ideal substance:
a perfect absorber of light: **“blackbody”**
absorbs all λ, reflects none
Q: what would such a thing look like?
Q: what are real substances almost like this?
Q: what everyday object is nearly the opposite of this?

blackbody absorbs radiation $\rightarrow$ heats $\rightarrow$ re-emits according to T
“blackbody radiation” $=$ thermal radiation
spectrum depends only on T
diagram: Flux F vs λ

perfect absorber of light: “blackbody”
absorbed energy $\rightarrow$ heats up
re-emits according to temperature T
“blackbody radiation” $=$ thermal radiation

Aside: Temperature Scales

everyday temperature scales:

• Farenheit: water freezes at 32°F, boils at 212°F

• Celcius/Centigrade: water freezes at 0°C, boils at 100°C

connection:

$$T(\mathrm{F}) = \frac{9}{5} T(\mathrm{C}) + 32^\circ \tag{1}$$

In both scales, negative temperatures exist, not mysterious

Turns out: there is a *lowest possible temperature*

→ "**absolute zero**" at -273°C $= -459^\circ$F

define **Kelvin** scale

$$T(\mathrm{K}) = T(\mathrm{C}) + 273^\circ \tag{2}$$

so $T(\mathrm{K}) = 0$ at absolute zero

room temperature $\approx 30^\circ$]C ≈ 300 K

Thermal Spectrum: Light as Thermometer!

peak λ is color seen: $\lambda_{\text{peak}} \propto 1/T$

where T is *absolute* temperature in Kelvin

recall: $T_{\text{Kelvin}} = 273 + T_{\text{Celsius}}$

hotter $\rightarrow$ more blue $\rightarrow$ shorter λ

"Wien's Law"

Turn the equation around: $T \propto 1/\lambda_{\text{peak}}$, namely

$$T = 3000 \text{ K} \left(\frac{10^{-6} \text{ m}}{\lambda_{\text{peak}}} \right) \tag{3}$$

so: can find T just from light!

$\Rightarrow$ spectrum as **thermometer**

color measures temperature

example: the Sun

`www: solar spectrum`

Sun's spectrum peaks in middle visible wavelengths:

$\lambda_{\text{peak,Sun}} \approx 500 \text{ nm } = 5 \times 10^{-7} \text{ m}$

$$\begin{aligned} T_{\text{Sun}} &= 3000 \text{ K} \left(\frac{10^{-6} \text{ m}}{\lambda_{\text{peak,Sun}}} \right) = 3000 \text{ K} \left(\frac{10^{-6} \text{ m}}{5 \times 10^{-7} \text{m}} \right) && (4) \\ &= 6000\text{K} \approx 10,000^\circ \text{ F} && (5) \end{aligned}$$

toasty!

Q: but the Sun is not all at one temperature–what has this T?

Q: does Wien's Law apply to people?

Q: what about Illini fans–blue shirt vs orange shirt?

note: sunlight comes from Sun surface ("photosphere")
$\rightarrow$ we have found $T_{\rm Sun,surfac}$ $\rightarrow$ even hotter inside!

Humans and thermal radiation:
we are not at zero temperature–can and do radiate!
but infrared–invisible to naked eye, very visible to IR sensors
`www: IR humans`
But note: T-Shirt color $\neq$ thermal radiation (good thing!)
reflected light, not glow from heat!

Thermal Radiation and galaxies:
`www: M104 galaxy image--visible light vs IR`
Q: compare–what's going on?

∞

Moving Light Sources: Doppler Effect

moving wave source $\rightarrow$ *change* in λ
observed color $\lambda_{\rm obs} \neq$ emitted color $\lambda_{\rm em}$

`www: Doppler animation`

- ▷ source approaching $\Rightarrow$ λ shorter: **blueshift**
- ▷ source receding $\Rightarrow$ λ longer: **redshift**

Q: why is this fantastically useful for astronomers (and cops)?

Dopper $\rightarrow$ detect motions and even measure speed
just by looking!

shift depends only on
relative motion in **radial** direction ("line of sight")
towards observer

Approximate expression

$$\frac{\lambda_{\text{obs}} - \lambda_{\text{em}}}{\lambda_{\text{em}}} = \frac{\Delta\lambda}{\lambda_{\text{em}}} = \frac{v}{c} \tag{6}$$

where v is radial speed
formula usually good enough (i.e., as long as $v/c \ll 1$)
Q: what's going on if $\Delta\lambda < 0$*?*

Observer's Scorecard

You can see an awful lot, just by looking.
– Cosmologist Yogi Berra

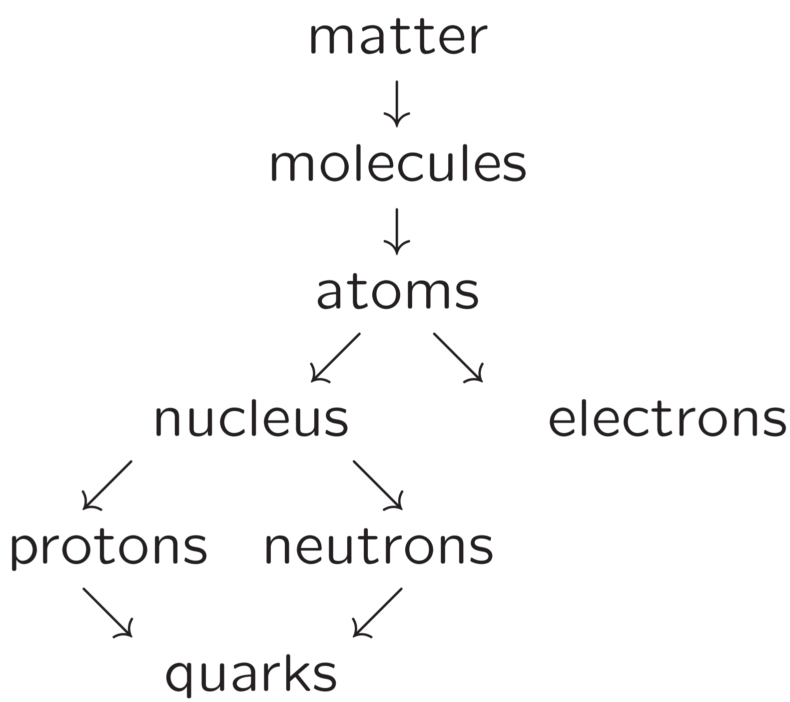
Clever measurements of light can reveal

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

Now go for the trifecta:
Q: how can we get composition (ingredient list) from light alone?
A: read the barcode!

Matter*

All known substances ever found in any lab
have the following structure



*Fine print: wierdo dark matter not covered by this discussion!

iClicker Poll: Atoms in a Grain of Sand

Think of the smallest grain of sand between your toes
at the beach

Go with your gut, vote your conscience!
Pick the *largest* answer that works

the number of atoms in 1 grain of sand is:

A more than the number of people in this room

B more than capacity of sold-out Memorial Stadium

C more than the Chicagoland population

D more than the population of Illinois

E more than population of planet Earth

Answer: 1 grain of sand has about 10^{19} atoms

that is: 10,000,000,000,000,000,000 atoms

$\gg$ global population $\approx 6.5 \times 10^9$ people

lesson $\Rightarrow$ atoms are **numerous** and **tiny**!

Atom Structure one or more **electrons** orbit a single **nucleus**

electron (e): electric charge -1

nucleus: made of protons (charge +1) & neutrons (charge 0)

mass: $m_p \approx m_n \approx 2000 m_e$

$\Rightarrow$ most of atom mass is in dense nucleus

$\Rightarrow$ most of atom volume occupied by electron orbits

total charge of atom: set by # electrons

$\# \, e = \# \, p \rightarrow$ neutral

$\# \, e = \# \, p - 1 \rightarrow$ charge = +1: singly ionized etc.

e moves around nucleus

Q: what does this tell us about forces in atoms?

orbits: curved paths – motion must be accelerated
$\rightarrow$ needs to be a net force–and there is!
nucleus & e attracted by **electric** force
rule: opposite charges attract, like charges repel

atom structure similar to Solar System:
attractive force $\rightarrow$ orbits
big object in center, orbiting smaller objects

charge of nucleus $\Rightarrow$ # p
sets force on e $\rightarrow$ orbit properties
determines chemical properties
92 atom varieties = **elements**
from hydrogen = $1p$ to uranium = $92p$
`www: periodic table`

Chemical Composition

different elements combine/react differently ⇒ chemistry
ex: water = H_2O = H-O-H

So: "what made of" = "chemical composition":
▷ what kinds of atoms?
▷ which are most, least numerous?

Examples
Sun, Jupiter: about 70% hydrogen, 28% helium, 2% other = "metals"
Earth: about 50% oxygen, 30% silicon, only 0.1% hydrogen