Astro 350

Lecture 7

Sept. 7, 2011

Announcements:

- HW2 due next time
- Discussion Question 2 due today

Please take and test-drive a diffraction grating slide

Last time:

Newton's laws and Newton's gravity

$\rightarrow$ combined to give a complete theory of solar system motions

(first) Copernican revolution

Cosmology with Newton

Great progress, many aspects quite modern:

- solar system motions understood exquisitely accurately
- masses of Earth, Sun, planets known
- stars understood to be other suns at great distances
  scale/size of cosmos huge and $\gg$ than Ptolemy imagined!

but still: at the time "Universe" = few thousand stars):
needed more powerful telescopes, and
better understanding of local "building blocks" – stars
$\Rightarrow$ need technology to understand star emission (light)
and star interiors (atoms)

Cosmologist's Toolbox: Outer Space

Most of what we will learn about cosmology
comes from studying object beyond earth

Q: take a minute, meet your neighbor, and make a list:
From earth,
What can we **directly** measure about planets/stars/galaxies?

What can we **directly** *measure about planets/stars/galaxies?*

Hard-nosed list:

- position on sky
- color/spectrum
- intensity/brightness
- time changes in the above (if any)

Other information (all the really interesting stuff!) is *indirect*!

Lesson:

$\Rightarrow$ can only measure light!

$\Rightarrow$ need to understand light and its interactions with matter to decode info

Last time:

- light = electromagnetic wave *Q: what does this mean?*
- characteristic properties

Light and Atoms: the Quantum Microworld

Light

Light deeply connected to
electric charge, electric and magnetic forces

Experiments show:
changing E force generates M force
changing M force generates E force

1. E&M linked: "electromagnetic force"

2. EM disturbances can travel through space:
   each regenerates the other: E $\rightarrow$ M $\rightarrow$ E $\rightarrow$ M $\rightarrow$ ...
   electromagnetic waves = "EM radiation"

light is a type of **wave**:

a wave is oscillating disturbance in a medium
wave can travel, medium does not
Demo: the wave!

snapshot in space, taken at one instant of time:
diagram
wavelength $\boxed{\lambda}$ size of one cycle
$\rightarrow$ wave "ID number"

intensity $\boxed{\mathrm{I}}$
"strength" of wave = "height of peaks"
Demo: slinky: same wavelength, diff't intensities

Q: Sound waves: how do we experience λ? I?
Q: Light waves: how do we experience λ? I?

Sound:

$\lambda \leftrightarrow \boxed{\text{pitch}}$

high pitch (treble): small λ

low pitch (bass): large λ

intensity = loudness

Light:

$\lambda \leftrightarrow \boxed{\text{color}}$

visible light: larger λ: more red

smaller λ: more blue intensity = brightness

The Speed of Light

Light is very fast!
So fast that it was a feat to measure the speed in lab
now known quite well

$$c = \text{constant} = 299,792,458 \text{ m/s}$$
$$= 3.0 \times 10^8 \text{ m/s} = 186,000 \text{ miles/s} = 6.7 \times 10^8 \text{ miles/hr}$$

enormous–but not infinite!
→ finite speed of light hugely important for astronomy
→ telescopes are time machines *Q: how?*

note: light speed c is *same* for all λ
Q: what would happen if this were not true?

The Electromagnetic Spectrum

EM waves can have λ outside of visible range

`www: EM spectrum`

IN general, light is combination of pure waves
with different λ

distribution of intensities:
different brightness at diff. λ: **spectrum**

diagram: sketch spectrum axes
Q: spectrum of laser pointer?
Q: spectrum of white light?

Technology Tim's Terminology Tip: "Radiation"

Warning!
meaning of "radiation" in Physics, Astronomy, Cosmology
$\neq$ "radiation" in everyday parlance!

In Physics, Astronomy, Cosmology...and more importantly...
In this course and on the exams:
radiation = movement of energy through space
carried by particles or waves

Examples:
ordinary visible light! e.g., flashlight, sunlight, starlight, ...
completely benign and indeed necessary for life!
but also invisible EM waves: radio, UV, X-ray...
and even non-EM particles: neutrinos...

Beware Confusion: "radiation" so defined $\neq$ radioactivity!
more on radioactivity later...

Thermal Radiation

hot objects glow (think stove burner)
temperature – radiation connection

microscopic picture:
temperature $\rightarrow$ atom motion

but atoms made of charged particles
motion $\rightarrow$ changing EM forces $\rightarrow$ light

thermal body (at some temp T)
emits EM radiation: which λ emitted?

iClicker Poll: Is Red-Hot Really Red?

Lightbulb on low power: wire appears to glow red
but look at glow through prism (diffraction grating)

What colors will you see?

A red only

B red and orange

C red, orange, and yellow

D red, orange, yellow, green

E red, orange, yellow, green, blue

spectrum of light; depends on T

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

Thermal Spectrum: Light as Thermometer!

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

where T is *absolute* temperature in Kelvin

recall: $T_{\text{Kelvin}} = 273 + T_{\text{Celsius}}$; room temp ≈ 290 K

hotter $\to$ more blue $\to$ shorter λ

"Wien's Law"

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

$$T = 3000 \text{ K} \left(\frac{10^{-6} \text{ m}}{\lambda_{\text{peak}}} \right) \tag{1}$$

so: can find T just from light!

$\Rightarrow$ spectrum as **thermometer**

color measures temperature