RELATIVITY

1. Special Relativity
2. Time Dilation
3. Doppler Effect
4. Length Contraction
5. Twin Paradox
6. Electricity and Magnetism
7. Relativistic Momentum
8. Mass and Energy
9. Energy and Momentum
10. General Relativity

DOPPLER EFFECT

- We have previously encountered the Doppler effect.
  - increase in pitch of sound when a source approach us (or we approach the source)
  - decrease in pitch when the source recedes from us (or we recede from the source)

The changes in frequency constitute the Doppler Effect

What is the origin of the Doppler effect?

DOPPLER EFFECT

The relationship between the source frequency ν_o and the observed frequency ν is:

$$\nu = \nu_o \left(\frac{1 + \upsilon / c}{1 - V / c} \right)$$

Where…

c = speed of sound
υ= speed of observer (+ for motion toward the source, - for motion away from it)
V = speed of the source (+ for the motion toward the observer, - for motion away from him)

DOPPLER EFFECT

Does the Doppler effect violate the principle of relativity?

Let us look at the Doppler effect relationship..

$$\nu = \nu_o \left(\frac{1 + \upsilon / c}{1 - V / c} \right)$$

The Doppler effect in sound varies depending on whether the source, or the observer, or both are moving.

So does it violate the principle of relativity?

DOPPLER EFFECT

Does the Doppler effect violate the principle of relativity?

NO!

Sound waves occur only in a material medium such as air or water, and this medium is itself a frame of reference with respect to which motions of source and observer are measurable.

How is that different for light?

DOPPLER EFFECT

How is that different for light?

No medium is involved and only relative motion of source and observer is meaningful.

THE DOPPLER EFFECT IN LIGHT MUST DIFFER FROM THAT IN SOUND

How can we find the Doppler effect in light?

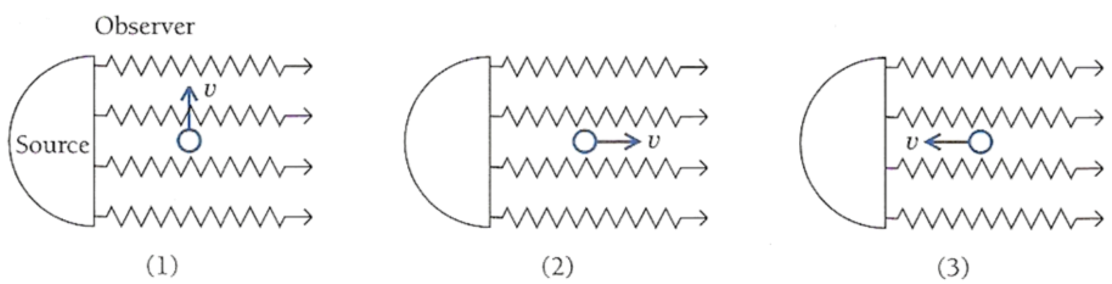
DOPPLER EFFECT

How can we find the Doppler effect in light?

Let us consider a light source as a clock that ticks ν_o times per second and emit a wave of light with each tick.

We will examine three situations:

1. Observer moving perpendicular to a line between him and the light source.
2. Observer receding from the light source.
3. Observer approaching the light source.



DOPPLER EFFECT

1. **Observer moving perpendicular to a line between him and the light source.**

- The proper time between ticks is $t_o = 1/\nu_o$.
- The time between a tick and the next in the reference frame of the observer is $t = t_o / \sqrt{1-\upsilon^2/c^2}$
- The frequency that the observer finds is:

$$\nu(transverse) = \frac{1}{t} = \frac{\sqrt{1-\upsilon^2/c^2}}{t_o}$$

Transverse Doppler effect in light is:

$$\nu = \nu_o \sqrt{1-\upsilon^2/c^2}$$

$$\nu \langle \nu_o$$

DOPPLER EFFECT

2. Observer receding from the light source.

- The observer travels a distance υt away from the source between ticks.
- The light wave from a given tick takes $\upsilon t/c$ longer to reach the observer from the previous one.
- The total time between the arrival of successive waves

$$T = t + \frac{\upsilon t}{c} = t_o \frac{1+\upsilon/c}{\sqrt{1-\upsilon^2/c^2}} = t_o \frac{\sqrt{1+\upsilon/c}}{\sqrt{1+\upsilon/c}} \frac{\sqrt{1+\upsilon/c}}{\sqrt{1-\upsilon/c}} = t_o \sqrt{\frac{1+\upsilon/c}{1-\upsilon/c}}$$

- The observed frequency is:

$$\nu(receding) = \frac{1}{T} = \frac{1}{t_o} \frac{\sqrt{1-\upsilon/c}}{\sqrt{1+\upsilon/c}} = \nu_o \sqrt{\frac{1-\upsilon/c}{1+\upsilon/c}}$$

$$\nu \langle \nu_o$$

No difference between who is moving (observer or source)

DOPPLER EFFECT

3. Observer approaching the light source.

- The observer travels a distance υt toward from the source between ticks.
- The light wave from a given tick takes $\upsilon t/c$ less time to reach the observer than the previous one.
- The total time between the arrival of successive waves

$$T = t - \frac{\upsilon t}{c}$$

- The observed frequency is:

$$\nu(approaching) = \nu_o \sqrt{\frac{1+\upsilon/c}{1-\upsilon/c}}$$

$$\nu \rangle \nu_o$$

No difference between who is moving (observer or source)

DOPPLER EFFECT

$$\nu(receding) = \nu_o \sqrt{\frac{1-\upsilon/c}{1+\upsilon/c}}$$

$$\nu(approaching) = \nu_o \sqrt{\frac{1+\upsilon/c}{1-\upsilon/c}}$$

Longitudinal Doppler effect in light

$$\nu = \nu_o \sqrt{\frac{1+\upsilon/c}{1-\upsilon/c}}$$

Sign convention $+\upsilon$ approaching and $-\upsilon$ receding

DOPPLER EFFECT

Example 1.2:

A driver is caught going through a red light. The driver claims to the judge that the color she actually saw was green (ν=5.60×10^{14} Hz) and not red (ν_0=4.80×10^{14} Hz) because of the doppler effect. The judge accepts this explanation and instead fines her for speeding at the rate of $1 for each km/h she exceeded the speed limit of 80 km/h. What was the fine?

DOPPLER EFFECT

The expanding universe

- The Doppler effect in light is an important tool in astronomy.
- Light emitted from stars have certain characteristics frequencies called spectral lines.
- The motion of a star shows up as a Doppler shift.
- spectral lines of distant galaxies are all shifted toward the low-frequency (red) end of the spectrum. ← red shift.
- Red shift indicate that the galaxies are receding from us and from one another.

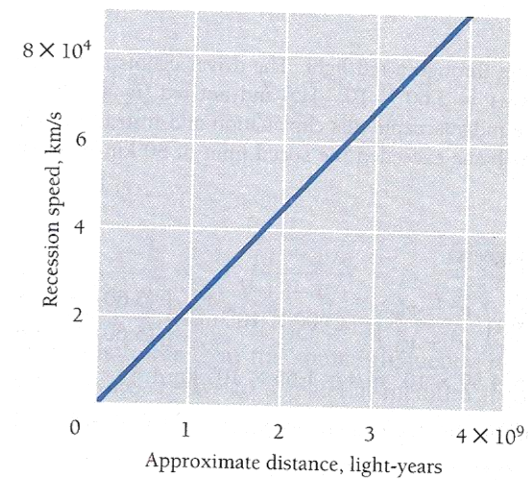
DOPPLER EFFECT

The expanding universe

• The speeds of recession are observed to be proportional to distance. ← i.e. the entire universe is expanding.

• This proportionality is called **Hubble's law**.

• According to the **Big Band** theory, the expansion began 13 billion years ago.



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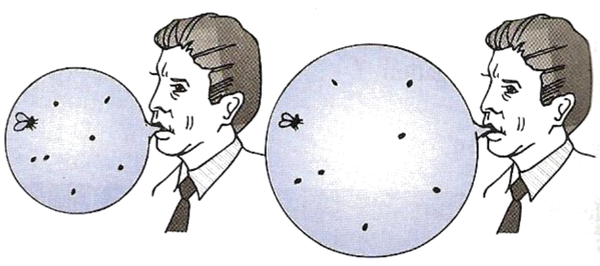

(b)

DOPPLER EFFECT

Example 1.3:

A distant galaxy in the constellation Hydra is receding from the earth at 6.12×10^7 m/s. By how much is a green spectral line of wavelength 500 nm (1 nm=10^{-9} m) emitted by this galaxy shifted toward the red end of the spectrum?

DOPPLER EFFECT

REMEMBER….

DOPPLER EFFECT HELPED US KNOW THAT THE UNIVERSE IS EXPANDING.