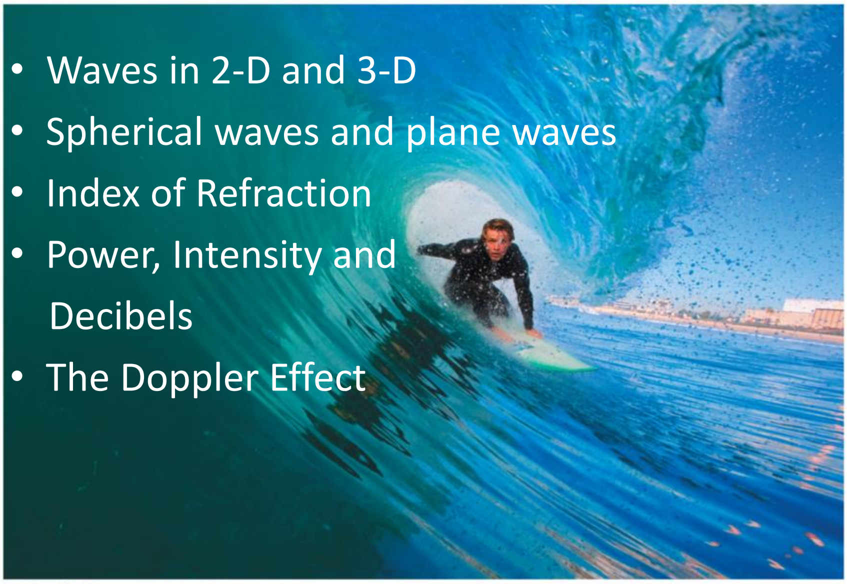
PHY132 Introduction to Physics II

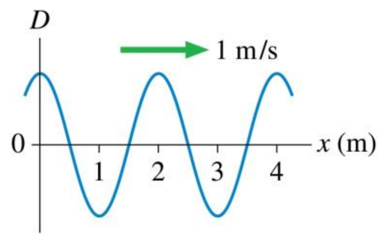
Class 2 – Outline:

- Waves in 2-D and 3-D
- Spherical waves and plane waves
- Index of Refraction
- Power, Intensity and Decibels
- The Doppler Effect



i-Clicker Discussion Question

The period of this wave is



A. 1 s.

B. 2 s.

C. 4 s.

D. Not enough information to tell.

The postal code of University of Toronto is M5S1A1.

Class 2 Preclass Quiz on MasteringPhysics

- This was due this morning at 8:00am
- 688 students submitted the quiz on time
- 51% of students answered correctly: The “phase” of a sinusoidal wave is the argument of the sine function (what is in the brackets)

"phase

$$D(x, t) = A\sin(kx - \omega t + \phi_0)$$

(sinusoidal wave traveling in the positive x-direction)

phase constant

- The phase, $\phi(x,t) = kx - \omega t + \phi_0$, is a function of both x-position and time.

$$D = A\sin\phi$$

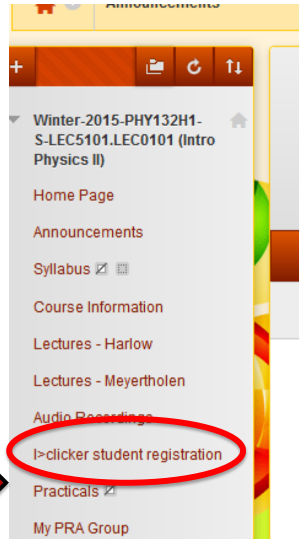
Class 2 Preclass Quiz on MasteringPhysics

- 89% answered correctly: The speed of light in a material is determined by the **index of refraction**.
- 92% answered correctly: When a source is moving away from an observer, the observed frequency is changed due to the motion (also the wavelength, but that was not a choice listed)
- 93% answered correctly: The sound intensity level in decibels is related to the **logarithm** of the intensity.
- 93% answered correctly: Human ears can detect frequencies in the range 20 Hz up to 20,000 Hz

Class 2 Preclass Quiz on MasteringPhysics

- Some common or interesting student comments/feedback:
- *"Do we need to re-register the iClicker if it's the same one we used last semester?*
- *ps. guess what I'm imitating: eeeeeee oooooouuu"*

  - YES! You must re-register! Registration is **free**, and done on portal.utoronto.ca.
  - Please do NOT register your clicker using the www.iclicker.com web-site.
  - Register here

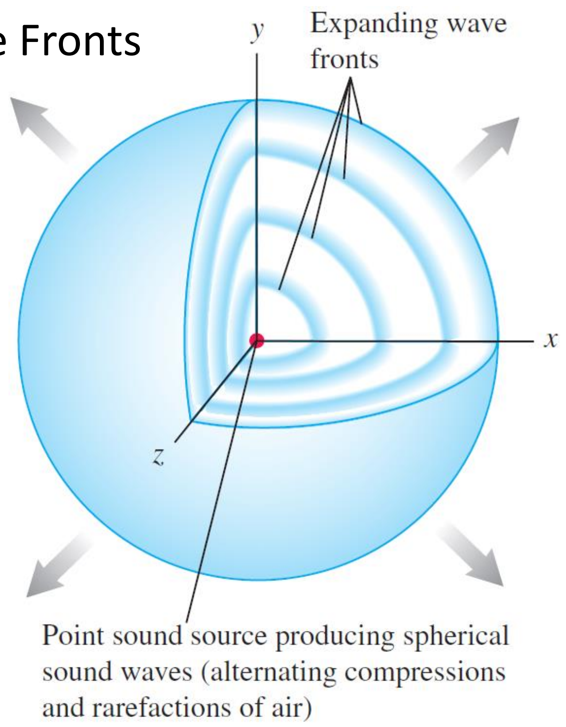


Class 2 Preclass Quiz on MasteringPhysics

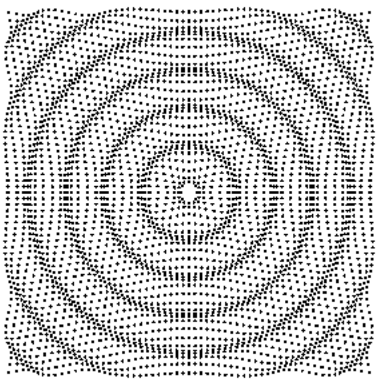
- The Doppler Effect. EEEEEEEEEEEeeeeeeeeeeeeeee

Waves and Wave Fronts

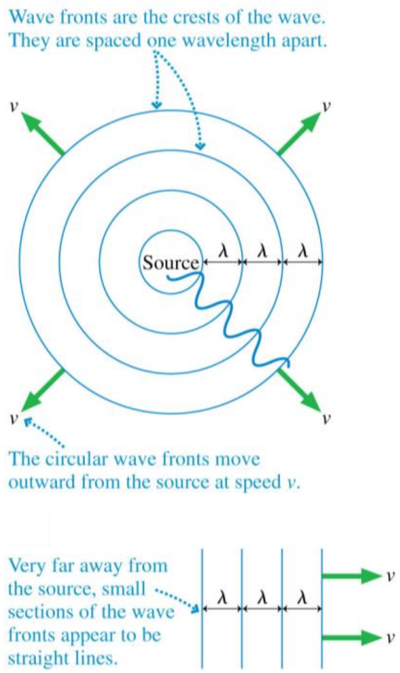
- A **wave front** is the locus of all adjacent points at which the *phase* of a wave is the same.
- Spherical wave fronts of sound spread out uniformly in all directions from a point source.
- Electromagnetic waves in vacuum also spread out as shown here.



Waves in Two and Three Dimensions

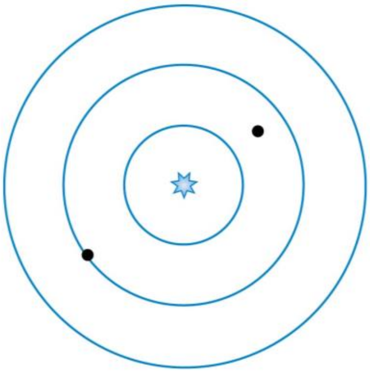


[Animation courtesy of Dan Russell, Penn State]



i-Clicker Discussion Question

A spherical wave travels outward from a point source. What is the phase difference between the two points on the wave marked with dots?



A. $\pi/4$ radians.
B. $\pi/2$ radians.
C. π radians.
D. $7\pi/2$ radians.
E. 7π radians.

The Index of Refraction

- Light waves travel with speed c in a vacuum, but they slow down as they pass through transparent materials such as water or glass or even, to a very slight extent, air.
- The speed of light in a material is characterized by the material's index of refraction n, defined as

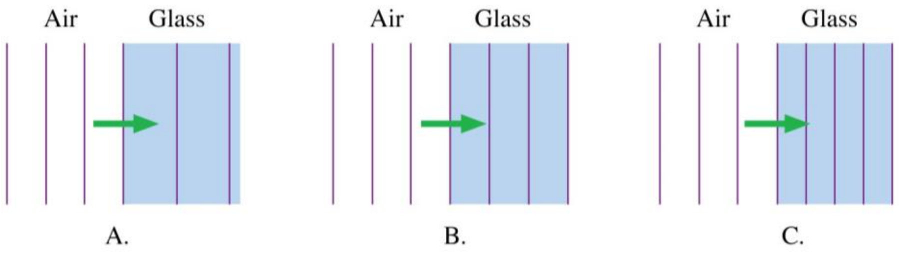
$$n = \frac{\text{speed of light in a vacuum}}{\text{speed of light in the material}} = \frac{c}{v}$$

Index of Refraction for various substances

Substance	Index of Refraction, *n*
Ice (H_2O)	1.309
Water (H_2O) at 20°C	1.333
Glycerine at 20°C	1.473
Crown glass (typical value)	1.52
Rock salt (NaCl)	1.544
Quartz (SiO_2)	1.544
Diamond (C)	2.417

i-Clicker Discussion Question

A light wave travels, as a plane wave, from air ($n = 1.0$) into glass ($n = 1.5$). Which diagram shows the correct wave fronts?



Index of Refraction and the Wave Aspects of Light

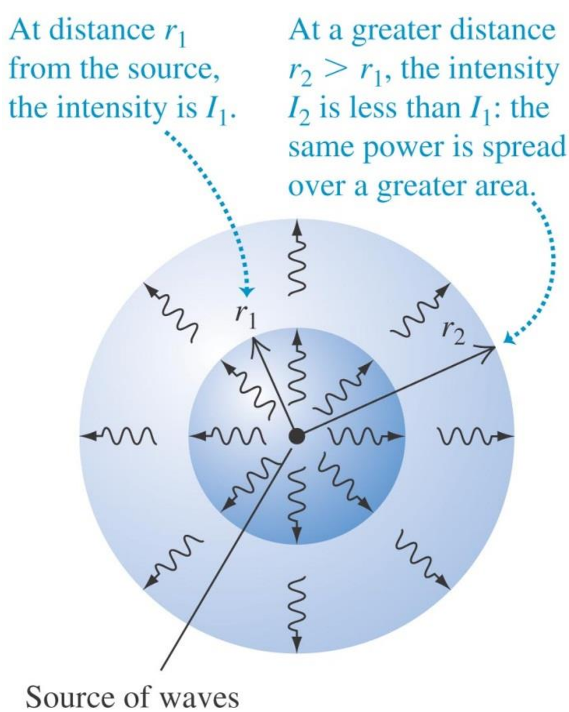
- The frequency f of a wave does not change when passing from one material to another.
- In any material, $v = \lambda f$; since f is the same in any material as in vacuum and v is always less than the wave speed c in vacuum, λ is also correspondingly reduced.

Wavelength of light in a material → $$\lambda = \frac{\lambda_0}{n}$$
λ_0: Wavelength of light in vacuum
n: Index of refraction of the material

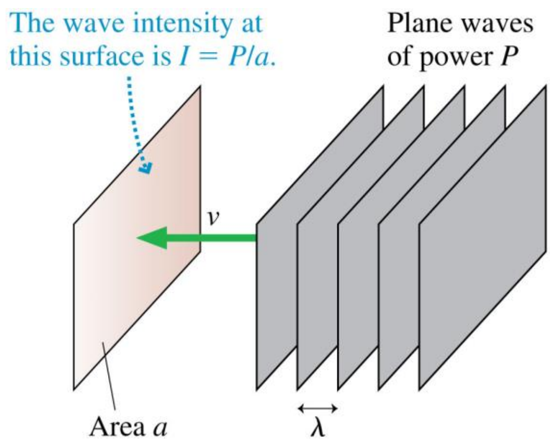
- When a wave passes from one material into a second material the waves get "squeezed" (the wavelength gets shorter) if the wave speed decreases and get "stretched" (the wavelength gets longer) if the wave speed increases.

Wave intensity

- The *intensity* of a wave is the average power it carries per unit area.
- If the waves spread out uniformly in all directions and no energy is absorbed, the intensity I at any distance r from a wave source is inversely proportional to r^2.



Power and Intensity



- When plane waves of power P impinge on area a, we define the **intensity** I to be:

$$I = \frac{P}{a} = \text{power-to-area ratio}$$

Example 20.9.
A laser pointer emits 1.0 mW $= 10^{-3}$ W of light power into a 1.0 mm diameter laser beam. What is the intensity of the laser beam?

$A = \pi r^2$

$r = \frac{d}{2} = 0.5 \times 10^{-3}$ m

$I = \frac{P}{A} = \frac{P}{\pi r^2}$

$I = \frac{10^{-3}\text{ W}}{3.14\,(0.5 \times 10^{-3})^2}$

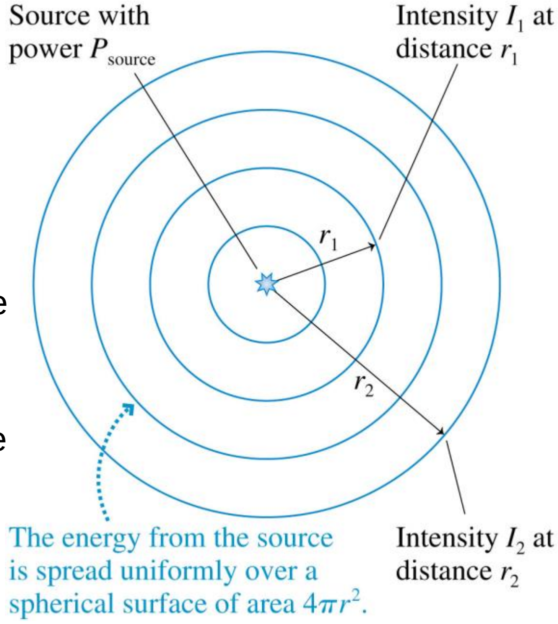
$= 1273$

$I = 1300 \frac{\text{W}}{\text{m}^2}$

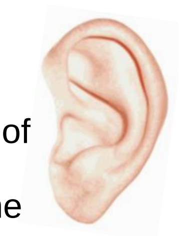
Intensity of Spherical Waves

- If a source of spherical waves radiates uniformly in all directions, then the power at distance r is spread uniformly over the surface of a sphere of radius r.
- The intensity of a uniform spherical wave is:

$$I = \frac{P_{\text{source}}}{4\pi r^2}$$



Intensity and Decibels



- Human hearing spans an extremely wide range of intensities, from the *threshold of hearing* at $\approx 1 \times 10^{-12}$ W/m^2 (at midrange frequencies) to the *threshold of pain* at ≈ 10 W/m^2.
- If we want to make a scale of loudness, it's convenient and logical to place the zero of our scale at the threshold of hearing.
- To do so, we define the **sound intensity level**, expressed in **decibels** (dB), as:

$$\beta = (10\text{ dB})\log_{10}\left(\frac{I}{I_0}\right)$$

where $I_0 = 1 \times 10^{-12}$ W/m^2.

Sound Intensity Levels – Representative Values

Source	Sound Intensity Level, β (dB)	Intensity, I (W/m^2)
Military jet aircraft 30 m away	140	10^2
Threshold of pain	120	1
Elevated train	90	10^{-3}
Busy street traffic	70	10^{-5}
Quiet radio in home	40	10^{-8}
Average whisper	20	10^{-10}
Threshold of hearing at 1000 Hz	0	10^{-12}

Intensity and Decibels

- From this morning's preclass quiz: *"I'm not sure how to answer "stop to think 20.6". Could you perhaps go over that in lecture? Thanks!"*
- Four trumpet players are playing the same note. If three of them suddenly stop. how much does the sound intensity level drop by?

$$\beta = (10\text{ dB})\log_{10}\left(\frac{I}{I_0}\right)$$

- **Answer:** ratio $(I_2/I_1) = ¼ = 0.25$: the actual intensity in Watts/m^2 has reduced by a factor of four. $\beta_2 - \beta_1 = 10\log\left(\frac{I_2}{I_0}\right) - 10\log\left(\frac{I_1}{I_0}\right)$
- Recall: $\log(a) - \log(b) = \log(a/b)$

$$\beta_2 - \beta_1 = 10\log\left(\frac{I_2\, I_0}{I_1\, I_0}\right) = 10\log_{10}(0.25) = 10(-0.6)$$

$$\beta_2 - \beta_1 = 6\text{ dB}$$

β has dropped by 6 dB.

i-Clicker Discussion Question

- A sound level of 10 decibels has 10 times more intensity than a sound level of zero decibels.
- A sound level of 20 decibels has ___ times more intensity than a sound level of zero decibels.

A. 10
B. 20
C. 50
D. 100
E. 200

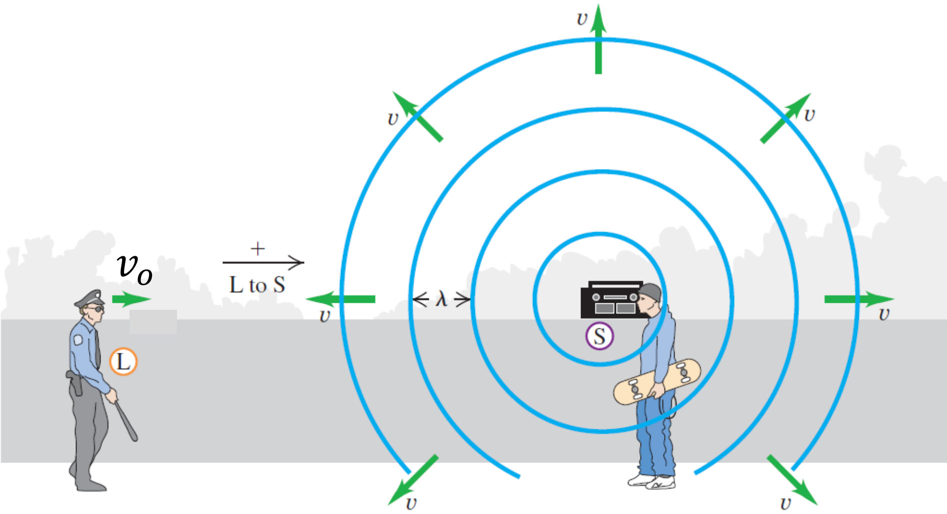
i-Clicker Discussion Question

- When you turn up the volume on your ipod, the sound originally entering your ears at 50 decibels is boosted to 80 decibels. By what factor is the intensity of the sound has increased?

A. 1 (no increase)
B. 30
C. 100
D. 300
E. 1000

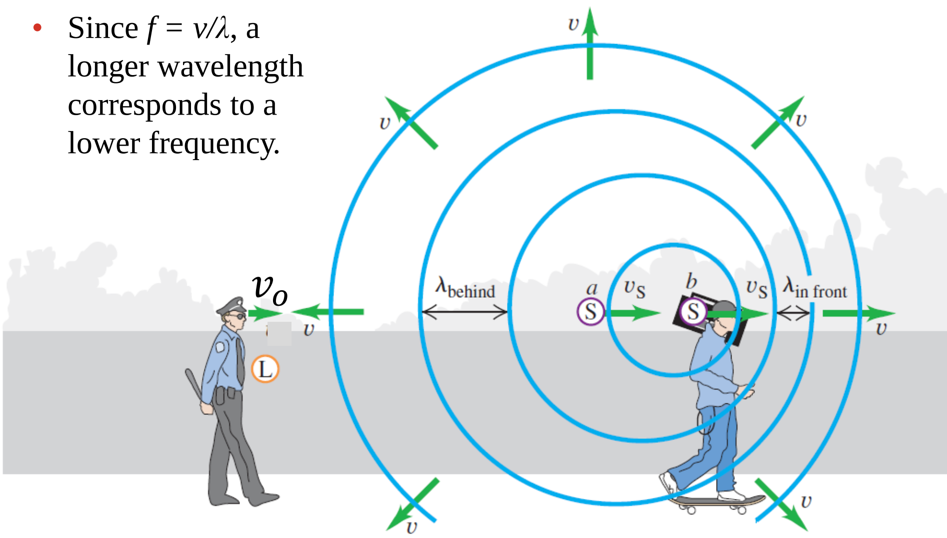
The Doppler effect: Moving listener

- An **observer** moving *toward* a stationary **source** hears a frequency that is *higher* than the at-rest frequency f_0.



The Doppler effect: Moving source

- When a **source** is moving *away* from an **observer**, the waves behind the source are stretched to a *longer* wavelength.
- Since $f = v/\lambda$, a longer wavelength corresponds to a lower frequency.



The Doppler effect

- The Doppler effect explains the observed change in pitch of the siren on a fire engine or ambulance.

- The frequency is high ($f > f_0$) when it is approaching you.
- The frequency is low ($f < f_0$) when it is moving away from you.

i-Clicker Discussion Question

Which statement is true?

Valerie is standing in the middle of the road, as a police car approaches her at a constant speed, v. The siren on the police car emits a "rest frequency" of f_0.

A. The frequency she hears rises steadily as the police car gets closer and closer.
B. The frequency she hears steadily decreases as the police car gets closer and closer.
C. The frequency she hears does not change as the police car gets closer.

i-Clicker Discussion Question

Which statement is true?

Valerie is standing in the middle of the road, listening to the siren of a police car approaching her at a constant speed, *v*. Daniel is listening to a similar siren on a police car that is not moving.

A. The frequency Daniel hears is lower than the frequency Valerie hears.
B. The frequency Daniel hears is higher than the frequency Valerie hears.
C. The frequencies that Daniel and Valerie hear are exactly the same.

The Doppler Effect

The frequencies heard by a stationary observer when the sound source is moving at speed v_0 are

$$f_+ = \frac{f_0}{1 - v_s/v} \quad \text{(Doppler effect for an approaching source)}$$

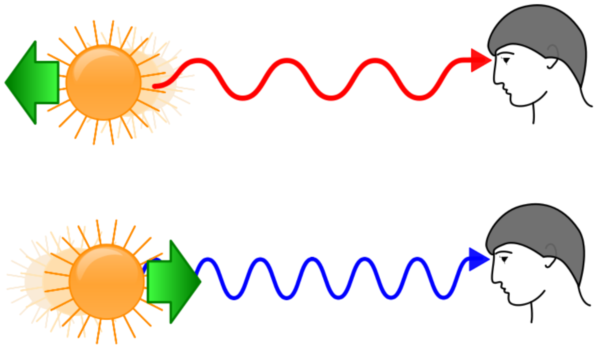
$$f_- = \frac{f_0}{1 + v_s/v} \quad \text{(Doppler effect for a receding source)} \qquad (20.39)$$

The frequencies heard by an observer moving at speed v_0 relative to a stationary sound source emitting frequency f_0 are

$$f_+ = (1 + v_o/v)f_0 \quad \text{(observer approaching a source)}$$

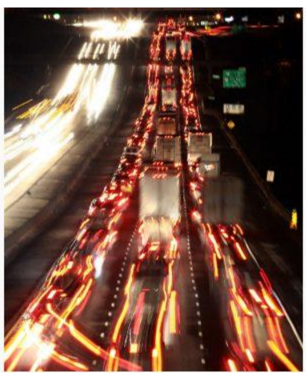
$$f_- = (1 - v_o/v)f_0 \quad \text{(observer receding from a source)} \qquad (20.40)$$

Doppler Shift for Light



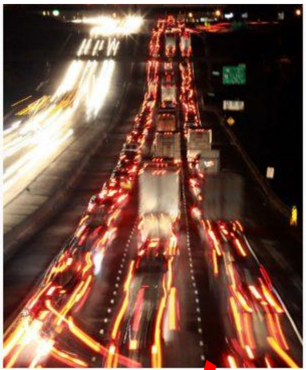
- When a light source is moving away from you, the spectrum is shifted toward the red.
- When a light source is moving toward you, the spectrum is shifted toward the blue.

Doppler Shift for Light



- The Doppler shift can be observed in the headlights of cars on the highway.
- The cars moving away from you appear more red, while the cars moving toward you appear more blue-ish or white.

Doppler Shift for Light

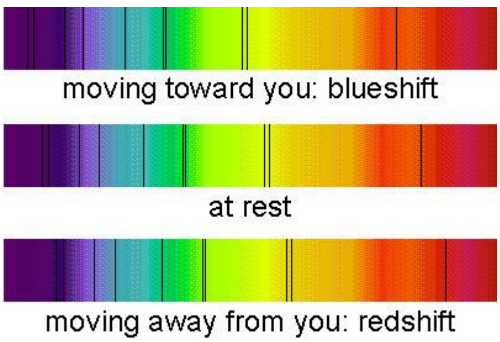


wthhh hhhhh hhhh??

- The Doppler shift can be observed in the headlights of cars on the highway.
- The cars moving away from you appear more red, while the cars moving toward you appear more blue-ish or white.

wrong

Doppler Shift for Light (yes, really!)



- The Doppler shift can be observed with carefully obtained spectra of very fast moving objects like stars
- There is a slight shift in “absorption lines”

Before Class 3 on Monday

- Please read Knight pages 591-603: Ch. 21, sections 21.1-21.4
- Please do the short pre-class quiz on MasteringPhysics by Sunday evening.
- Something to think about: What is the difference between a traveling wave and a standing wave. Does a standing wave really stand still?