

**Which part of today's assignment was particularly hard or confusing?**

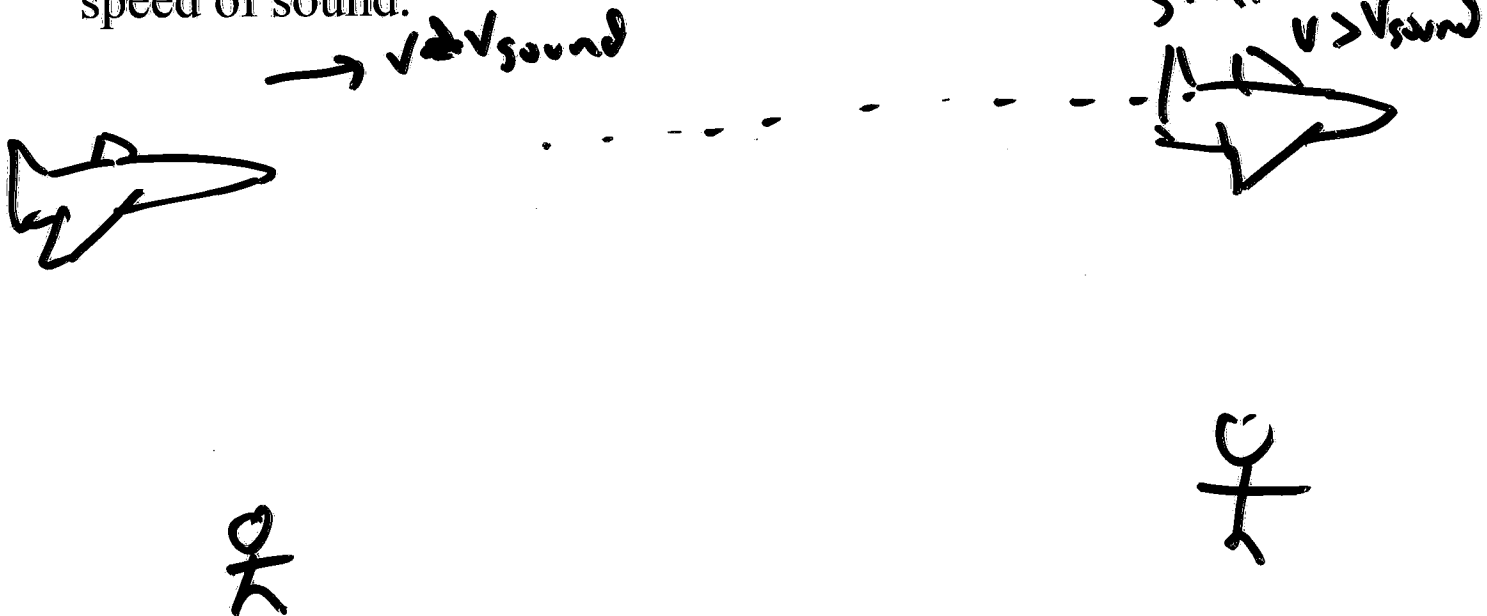
PLEASE emphasize the  $v$  and  $v$ -sub- $o$   $v$ -sub- $s$  stuff and how you can tell what the sign should be and the relationships between them in the [Doppler effect] equations.

I don't understand the warm-up question about the sonic boom. Both answer choices seem like the same thing.

**Warmup:** You hear a sonic boom:

◦ when an aircraft above you first exceeds the speed of sound ("breaks the sound barrier")

◦ whenever the aircraft flies overhead faster than the speed of sound.



## Any other comments:

Will the TAs be holding a final study session? When??

My wife made really thick milkshakes for dinner last night, and we noticed that if we sucked them up a straw and then moved away, the milkshake stayed exactly where it was in the straw (whereas water would have moved down). With what we know about pressure, hydraulic car lifts, etc., I'm a little confused as to why the milkshake didn't just slide down the straw.

Is having a note card for the final debatable? **No**

What should we study for the final? I thought that it was pretty straightforward with the midterms how you broke it down by priority with the list (homework, lectures, iclicker quizzes, pre-quizzes, extra-problems, etc.). I was thinking of just going over all of the lectures and pre-class quizzes and the homework over the new material and just skip doing all of the homework problems for the entire semester as it would be too time-consuming. Also, if time permits, go over the old exams and practice exams. What are your thoughts?

- old exams ✓
- HW problems (likely)
- warm ups ✓
- lots of other ones

$$a) \frac{9.8 (5)^2}{3}$$

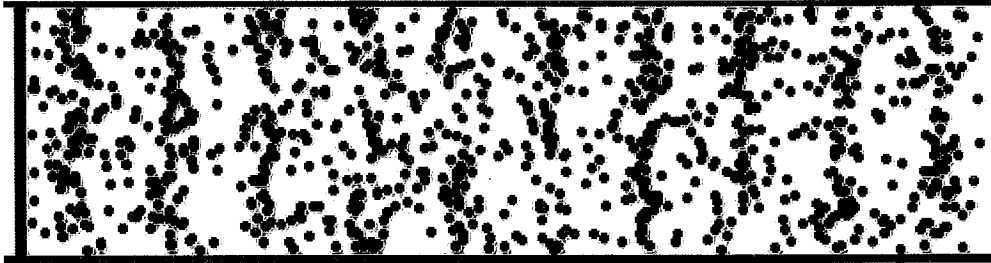
$$b) \frac{9.8 (3^2)}{5}$$

**What's wrong with this video?** Star Wars, Battle of Yavin

**What is sound?**

Kind of like this:

*longitudinal*



...but not really. **What** is oscillating? (not exactly the molecules)

*pressure*

What type of oscillation is it?

Demo: Vacuum jar

Audible sound waves:  $\sim 20$  Hz to  $\sim 20$  kHz (different for everyone)

Hearing test! Demo: frequency source & speaker

How is sound produced?

- Speaker cutaway
- Tuning fork demo
- Air jet and spinning disk demo
- Vocal folds (“cords”) demo
- “singing rod” demo

# Speed of sound

## Solids

Recall for strings,  $v = \sqrt{\frac{T}{\mu}}$  (transverse waves)  
*Tension*  
*mass density*

Longitudinal waves in a thin rod:  $v = \sqrt{\frac{Y}{\rho}}$

Y is Young's modulus, related to a 1D stress

Longitudinal waves in general:  $v = \sqrt{\frac{B}{\rho}}$

B is the bulk modulus (resistance to 3D "squeezing")

Solids vs liquids: sound is faster in solids because they are "stiffer" (less "spongy")  
large B

Aluminum 5100 m/s

Water 1500 m/s

Gases: Air:  $v = 343$  m/s at  $20^\circ$  C

To impress your date:  
~1 km in 3 sec

Other temps:  $v = 331$  m/s  $\sqrt{\frac{T}{273K}}$

Helium: 972 m/s (at  $0^\circ$  C) Why so much faster?  
*smaller m, faster ✓*

# Intensity (loudness)

Definition  $I = \frac{\text{Power}}{\text{Area}}$

Intensity vs distance?

For a *spherically* emitting source:

$$I = \frac{P}{A} = \frac{P}{4\pi r^2}$$

$$\text{so } \frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}$$



**Clicker quiz:** You measure the sound intensity produced by a spherical speaker to be  $10 \text{ W/m}^2$  at a distance of 1.5 meters. What will be the intensity at 3 meters away?  $\frac{1}{4}(10) \text{ W/m}^2$

- a. 2.5    b. 5    c. 10    d. 20    e. 40

double the distance  $\rightarrow \frac{1}{4} I$

What is the total sound power being produced by the speaker?

$$P = I \cdot A \\ = 10 \frac{\text{W}}{\text{m}^2} (4\pi (1.5\text{m})^2) = \underline{\hspace{2cm}}$$

# Decibel intensity scale

- We hear over a huge range of intensities
- So use *base 10 logarithmic scale*: decibel number  $\beta$

"beta"

→ **adding ten to dB number =  $\times 10$  to the intensity**

$$\text{decibel number} = \beta = 10 \log \frac{I}{I_0} \quad \text{where } I_0 = 10^{-12} \text{ W / m}^2$$

$$\text{solving for I: } I = I_0 \left( 10^{\beta/10} \right)$$

		W/m <sup>2</sup>	dB
Jet on runway	Instant pain, damage	1000	150
Machine gun	damage	10	130
Rock concert (best seats)	pain, damage	1	120
Power mower	damage (if all day)	10 <sup>-2</sup>	100
Vacuum cleaner	safe all day	10 <sup>-5</sup>	70
Conversation		10 <sup>-7</sup>	50
Whisper		10 <sup>-9</sup>	30
Rub fingers by ear	Threshold	10 <sup>-12</sup>	0

10x more I  
10 =  $\beta$

## Mythbusters: jet on a runway

<http://www.youtube.com/watch?v=eTQh7D-nDNM> start at 2:48

...of course, the intensity also depends on the distance away...

OSHA regulations:  $\leq 90$  dB averaged over 8 hour day.

# Logarithm Review (base 10)

$\text{Log}_{10}(x)$  is the inverse of  $10^y \rightarrow$  if  $x = 10^y$  then  $y = \log_{10}(x)$

I.e. "10 to the what equals 22?" answer: 1.3424 ( $\log(22)$ )

Review of "Laws of Logs":

$$10^{1.3424} = 22$$

1.  $\log(ab) = \log(a) + \log(b)$

2.  $\log(a^n) = n \log(a)$

$\log(100) = ?$  Translation: 10 to what number equals 100?

2

$$\log(10^6) = 6$$

$$\log(10^6) = 6 \log 10 = 6$$

**Worked problem:** If  $\log(3) = 0.477$ , what is  $\log(300)$ ?

$$\begin{aligned} \log 300 &= \log(3 \cdot 100) \\ &= \log 3 + \log 100 \\ &= .477 + 2 \\ &= 2.477 \end{aligned}$$

# Decibels again

$$\beta = 10 \log \frac{I}{I_0}$$

$\beta$  = "decibel number"

$I_0 = 10^{-12} \text{ W/m}^2$  **10x2**

Compare two intensities:

If you increase  $I$  by a factor of 10, add 10 to  $\beta$

If you increase  $I$  by a factor of 100, add 20 to  $\beta$

If you increase  $I$  by a factor of 1000, add 30 to  $\beta$

→ **each factor of ten added to dB number =  $\times 10$  to the intensity**

If you increase  $I$  by a factor of 2, add 3 to  $\beta$

$[\log(2) = 0.301]$

$10 (.3) = 3$

**Clicker quiz:** If you increase  $I$  by a factor of 8, add 9 to the decibel level (Hint: do it with 2's)

a. 4

b. 6

c. 8

**d. 9**

e. 12

$I \times 2$

$\beta + 3$

$\times 2$

$\beta + 6$

$\times 2$

**$\beta + 9$**

**Worked problem:** You hear an average of 82 dB in your workshop as one printing press runs. The next day you come in and find the sound level to be 88 dB. How many total printing presses are now running? (Hint: what happens to  $\beta$  as you double the number of presses?) **dB : +6 → I :  $\times 4$**

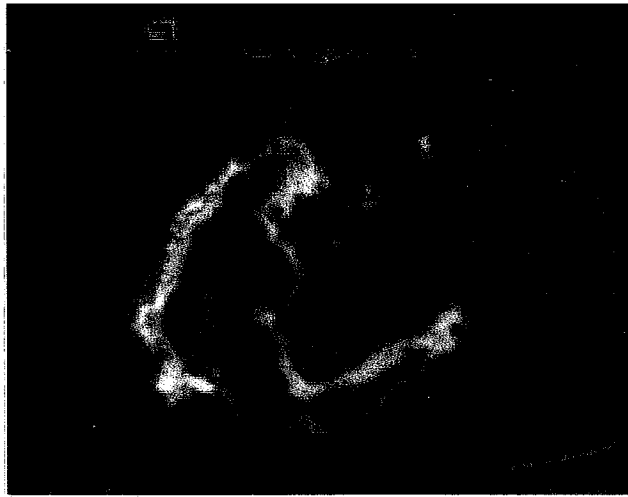
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# Doppler Shift—“Race Car Effect”

Applications:

Doppler ultrasound: blood flow imaging in heart



8 1/2 week embryo blood flow

Doppler radar

Frequency is increased when the source and observer approach each other, decreased when they go away from each other.

Demo: Doppler speaker

Demo: Come, Come, Ye Saints <http://stokes.byu.edu/bells.wav>

**Ralph recently saw this bumper-sticker on a professor's car: "If this sticker is blue, you're driving too fast!" (True story: a professor at my previous university had the sticker on her car.) The sticker looks RED to him. He is confused. Can you explain the joke to Ralph?**

when you travel that fast, then you increasing the <sup>rate</sup> speed at which the waves hit you. So they appear to be going <sup>at a</sup> faster ~~rate~~ ROYGBIV. Blue is higher up so it appears to be blue. <sub>rate</sub>

...If you move fast enough, the frequency of the red wavelength can be interpreted as a blue wave length ~~in your mind~~ and appear blue. A similar principle is used to measure how far away stars are in the galaxy.

It is called 'red-shift' (or 'blue-shift' depending on which way you go)—as you travel towards light you run into the waves faster, so it appears like blue light--if you are moving away from the source the spacing of the waves appears more spread out so it looks red. The sticker part is a joke designed to make those who get it feel clever--you have to be moving FAST for this to be noticeable.

Astronomers make use of this to measure speeds of things like stars.

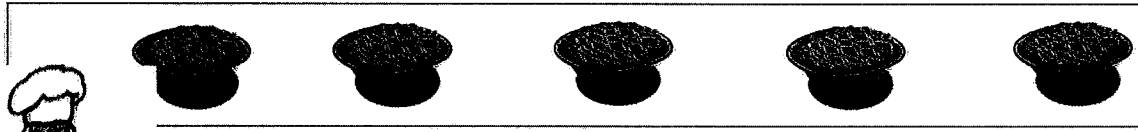
how fast?  
a substantial fraction of speed of light

$\lambda$

$f = \frac{\# \text{pies}}{\text{sec}}$

The pie factory conveyor belt:

$v_{\text{belt}}$



lady

$$v = f\lambda$$

$f = v/\lambda$  or  $\lambda = v/f$  the spacing between pies

baker

$v_s$  source speed

baker's speed  
lady's speed

$v_o$  observer speed

$v$  speed of sound (pies)  $v_{\text{belt}}$

If **observer moves** toward source (pie maker), she would measure the same  $\lambda$  but the pies are coming at her at higher frequency

If **source moves** toward observer, the  $\lambda$  shrinks, but the pie  $v$  doesn't change

observer  $f = \frac{v}{\lambda}$

increases!

**Both source and observer can move**

[http://stokes.byu.edu/doppler\\_script\\_flash.html](http://stokes.byu.edu/doppler_script_flash.html)

Equation: 
$$f' = f \left( \frac{v \pm v_o}{v \pm v_s} \right)$$

if lady moving towards  $v + v_o$   
if baker moving toward  $v - v_s$

Choose your signs **carefully!!**

→ Make sure new  $f >$  old  $f$  when:

they are moving towards!

# Review quizzes

**Clicker quiz 1:** The *intensity* of a wave is its

- a. power
- b. power/area
- c. power  $\times$  area
- d. area/power

**Clicker quiz 2:** If a loudspeaker emits spherical sound waves in all directions, what *decreases* as you go farther away from the loudspeaker? (very slowly)

- a. wavelength
- b. intensity (loudness)
- c. frequency

**Clicker quiz 3:** True/false: if you double the sound intensity, the decibel number also gets doubled.

- a. true
  - b. false
- +3 to dB number

**Clicker quiz 1:**  $10^{-4}$  W/m<sup>2</sup> has a dB level of \_\_\_\_\_ dB.

- a. 4    b. 8    c. 60    **d. 80**    e. 90

$$\beta = 10 \cdot \log \frac{I}{10^{-12}} = 10 \log 10^8$$

**Clicker quiz 2:** Two plastics (A and B) have the same density, but plastic A is 16 times harder to compress; that is, it compresses 1/16 as much for the same applied pressure. Which has the *greatest speed of sound*?

- a. A**    b. B

larger Bulk modulus

**Clicker quiz 3:** A siren emitting at 200 Hz is on a car going *very* fast toward you at 1/2 the speed of sound (take the speed of sound to be 300 m/s here). You travel away from the car on your bike at 1/3 the speed of sound. The frequency you hear is \_\_\_\_\_ Hz

- a. 150    b. 200    c. 250    d. 267    e. 330

$$f' = f \frac{v \pm v_o}{v \pm v_s}$$
$$= 200 \left( \frac{300 - \frac{1}{3} 300}{300 - \frac{1}{2} 300} \right)$$
$$= \underline{\hspace{2cm}}$$