sound waves, problem set #2

1) A fan at a rock concert is at a point with sound intensity level $\beta = 120$ dB. Sound waves causes the eardrum to vibrate. A typical eardrum is a circle with radius $R = 4.2$ mm.
a) Find the intensity in W/m^2 units.
b) How much energy is delivered to one of the eardrums each second?

a) $\beta = 10 \log \frac{I}{I_0} \rightarrow 120 \text{ dB} = 10 \log \frac{I}{1.0 \times 10^{-12} \frac{W}{m^2}} \Rightarrow I = 1.0 \frac{W}{m^2}$.

b) $I = \frac{\text{Power}}{\text{Area}}$ $\quad$ $\text{Area} = \pi (4.2 \times 10^{-3})^2 \, m^2 = 5.5 \times 10^{-5} \, m^2$

$\Rightarrow \text{Energy} = 1 \text{ sec} \times \text{Power} = 1 \text{ sec} \times 1.0 \frac{W}{m^2} \times 5.5 \times 10^{-5} \, m^2 = 5.5 \times 10^{-5} \text{ J}$.

2) Sound is detected when a sound wave causes tympanic membrane (the eardrum) to vibrate. Typically the diameter of this membrane is about 8.4 mm in humans. Someone whispers (20 dB) a secret in your ear.
a) What is the intensity of this sound in units W/m^2?
b) How much energy is delivered to the eardrum in each second?

Similar to 1.

3) On the planet Arrakis a male ornithoid is flying toward his mate at velocity 25.0 m/s while singing at a frequency of 1200 Hz. If the stationary female hears a tone of 1240 Hz, what is the speed of sound in the atmosphere of Arrakis?

$v_L = 0$

$v_S = 25.0$ m/s

and $f_L > f_S$; $f_L = 1240$ Hz, $f_S = 1200$ Hz

speed of sound

$\Rightarrow f_L = \frac{v}{v - v_S} f_S \rightarrow v = v_S \frac{f_L}{f_L - f_S} = 25 \frac{m}{s} \frac{1240 \text{ Hz}}{40 \text{ Hz}} = 775$ m/s .

0: $f_{bat} = 80$ kHz

4 Steps

1: bat sends f_1

2: reflector receives $f_2^{reflector}$

3: reflector sends $f_3^{reflector}$

4: bat receives $f_4^{reflector}$

4) Horseshoe bats emit sounds from their nostrils and then listen to the frequency of the sound reflected to find their own velocity or a prey's velocity. One of them is flying at speed $v_{\rm bat}$ and emits sound of frequency $f_{\rm bat} = 80$ kHz. The bat hears reflections at frequencies $f = 81, 82, 77$ kHz. All the reflections are coming form the front. One of these reflections is from another bat with velocity $v_{\rm other}$, one is from the walls and still objects, and one is from an insect which is our bat's dinner moving with velocity $v_{\rm insect}$ towards our bat. See fig. 1. Sound velocity is $v = 340$ m/s.

a) For the reflection from the wall in front, is the frequency higher or lower? Draw a small picture of wave crests. So which reflection[s] can be from the wall?
b) For the reflection from the insect, is the frequency higher or lower? Is this frequency higher or lower than the frequency reflected from the wall?
c) We know that the other bat is flying away from our bat going faster. Which reflection is from this other bat?
d) Now using the numbers, find $v_{\rm bat}$, $v_{\rm insect}$, and $v_{\rm other}$.

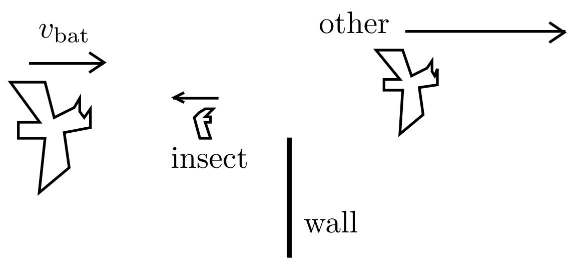

Figure 1: A bat echo-locating.

$f_2^{wall} = f_1$ $\quad f_3^{wall} = f_1$

wall reflects (receives & sends) with same freq.

bat sending

$\lambda_1 < \lambda_{bat} = \dfrac{v}{f_{bat}}$

bat $\to$ v_{bat})) or $f_1 > f_{bat}$ $\qquad$ f_1 ((| wall $\quad \lambda_1$

bat receiving

bat $\to$ v_{bat} ((

$\lambda_4^{wall} < \lambda_1$

or $f_4^{wall} > f_1 > f_{bat}$

a) f_4^{wall} : higher. So either 81 kHz or 82 kHz.

b) $f_2^{insect} > f_1 = f_2^{wall}$

$f_3^{insect} > f_2^{insect} > f_1 = f_2^{wall}$

$\Rightarrow f_4^{insect} > f_4^{wall} > f_1 > f_{bat} \to \begin{cases} f_4^{insect} = 82 \text{ kHz.} \\ f_4^{wall} = 81 \text{ kHz.} \end{cases}$

c) $f_1 > f_{bat}$ inc.

$f_2^{other} < f_1$ dec.

$f_3^{other} < f_2^{other}$ dec. if $v_{other} > v_{bat}$ we have more decreasing $\to$ $f_4^{other} = 77$ kHz.

$f_4^{other} > f_3^{other}$ inc.

d) v_r : reflector's velocity; positive if going away from source

$$f_1 = \frac{v}{v - v_{bat}} f_{bat}, \quad f_2 = \frac{v - v_r}{v} f_1, \quad f_3 = \frac{v}{v + v_r} f_2, \quad f_4 = \frac{v + v_{bat}}{v} f_3,$$

so $$f_{final} = f_4 = \frac{v + v_{bat}}{v - v_{bat}} \frac{v - v_r}{v + v_r} f_{bat}$$

wall : $f_4^{wall} = 81 \text{ kHz} = \dfrac{v + v_{bat}}{v - v_{bat}} 80 \text{ kHz} \Rightarrow v_{bat} = 2.1$ m/s,

insect : $f_4^{insect} = 82 \text{kHz} = \dfrac{v - v_r}{v + v_r} 81 \text{ kHz} \Rightarrow v_{insect} = -2.1$ m/s,

other : $f_4^{other} = 77 \text{kHz} = \dfrac{v - v_r}{v + v_r} 81 \text{ kHz} \Rightarrow v_{other} = 8.6$ m/s.