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## Discussion 12: Sound

### Summary

#### Sound Intensity

Intensity

Sound from a point source produced with power  $P$  has an intensity at distance  $r$  of  $I = \frac{P}{4\pi r^2}$ .

Decibel scale

The decibel scale is a logarithmic transformation of sound intensity. A sound with an intensity  $I$  has a decibel rating of  $\beta = (10\text{dB}) \log_{10}(I/I_0)$ , where  $I_0$  is the reference intensity of  $10^{-12} \text{ W/m}^2$ .

The difference in decibel ratings of two sounds with intensity  $I_1$  and  $I_2$  is

$$\beta_2 - \beta_1 = (10\text{dB}) \log_{10}(I_2/I_1)$$

The difference in decibel rating of sound from the same source observed at two different distances  $r_1$  and  $r_2$  is

$$\beta_2 - \beta_1 = (20\text{dB}) \log_{10}(r_1/r_2)$$

#### Doppler shift

The frequency  $f_D$  of sound received by the detector depends on the source frequency  $f_S$ , the velocity of the sound  $v$ , and the velocity of the source  $v_S$  and detector  $v_D$ . Adopting the convention that the positive direction is from the source toward the detector, the detected frequency is

$$f_D = f_S \frac{v - v_D}{v - v_S}$$

#### Heat and Temperature

**Heat** is energy transferred between two bodies because of a difference in temperature. The SI unit of heat is the *joule*. There are other units based on the increase in temperature of a substance when heat is added to it. The most familiar such unit is the *calorie*, which is the heat needed to raise the temperature of 1 gram of liquid water by 1 degree Celsius. 1 calorie = 4.184 joules.

#### Problems

1. The sound level at a Formula 1 race is reported to reach 140 decibels at trackside, about 10 m from the cars. Long-term exposure to sound levels above 80 dB damages hearing; sound levels above 110 dB are uncomfortable, and levels above 130 dB are painful.

Rodney Racefan has arrived at a Formula 1 race without his earplugs, and he doesn't want to pay for the expensive earplugs for sale at the track.

- a. How far from the track must Rodney stand to keep the noise he hears below the discomfort level of 110 dB?

- b. How far from the track must he stand to keep the noise he hears below 80 dB?
2. A spectator at a Formula 1 race (with proper hearing protection) notices that the sound from an approaching car has a frequency of 380 Hz, while the sound from the same car driving away has a frequency of 240 Hz. (The sound from a car is a combination of many frequencies and phases, but 380 and 240 Hz are the intensity maxima.) The speed of sound in air is 342 m/s.
- a. (5 points) What is the speed of the car? Assume that it has the same speed when it is driving toward the spectator as when it is driving away.
- b. (5 points) What is the frequency of the sound emitted by the car?
3. Let's look at the energy involved in heating water from room temperature (about 25 °C) to bath water temperature (about 40 °C).
- a. How much heat, in calories, must be added to 1.000 kilogram of 25 °C water to bring it to a bath water temperature of 40 °C
- b. How much energy is that in joules?
- c. If that amount of work is done to push 1.000 kilogram of water initially at rest, what is the water's final kinetic energy?
- d. What is the water's final speed?
- e. If that amount of work is done to lift 1.000 kilogram of water vertically, to what height is it lifted?