

55. (a) The expression for the Doppler shifted frequency is

$$f' = f \frac{v \pm v_D}{v \mp v_S},$$

where f is the unshifted frequency, v is the speed of sound, v_D is the speed of the detector (the uncle), and v_S is the speed of the source (the locomotive). All speeds are relative to the air. The uncle is at rest with respect to the air, so $v_D = 0$. The speed of the source is $v_S = 10 \text{ m/s}$. Since the locomotive is moving away from the uncle the frequency decreases and we use the plus sign in the denominator. Thus

$$f' = f \frac{v}{v + v_S} = (500.0 \text{ Hz}) \left(\frac{343 \text{ m/s}}{343 \text{ m/s} + 10.00 \text{ m/s}} \right) = 485.8 \text{ Hz} .$$

- (b) The girl is now the detector. Relative to the air she is moving with speed $v_D = 10.00 \text{ m/s}$ toward the source. This tends to increase the frequency and we use the plus sign in the numerator. The source is moving at $v_S = 10.00 \text{ m/s}$ away from the girl. This tends to decrease the frequency and we use the plus sign in the denominator. Thus $(v + v_D) = (v + v_S)$ and $f' = f = 500.0 \text{ Hz}$.
- (c) Relative to the air the locomotive is moving at $v_S = 20.00 \text{ m/s}$ away from the uncle. Use the plus sign in the denominator. Relative to the air the uncle is moving at $v_D = 10.00 \text{ m/s}$ toward the locomotive. Use the plus sign in the numerator. Thus

$$f' = f \frac{v + v_D}{v + v_S} = (500.0 \text{ Hz}) \left(\frac{343 \text{ m/s} + 10.00 \text{ m/s}}{343 \text{ m/s} + 20.00 \text{ m/s}} \right) = 486.2 \text{ Hz} .$$

- (d) Relative to the air the locomotive is moving at $v_S = 20.00 \text{ m/s}$ away from the girl and the girl is moving at $v_D = 20.00 \text{ m/s}$ toward the locomotive. Use the plus signs in both the numerator and the denominator. Thus $(v + v_D) = (v + v_S)$ and $f' = f = 500.0 \text{ Hz}$.