Physics 101

Lecture 25

Friday, March. 5, 2004

Topics: Doppler Effect

Beats

standing waves

Ref: 14-6, 7, 8, 9

- The Doppler effect

The observed frequency is shifted when there is a relative motion between the source and the observer.

- Case ①: No relative motion

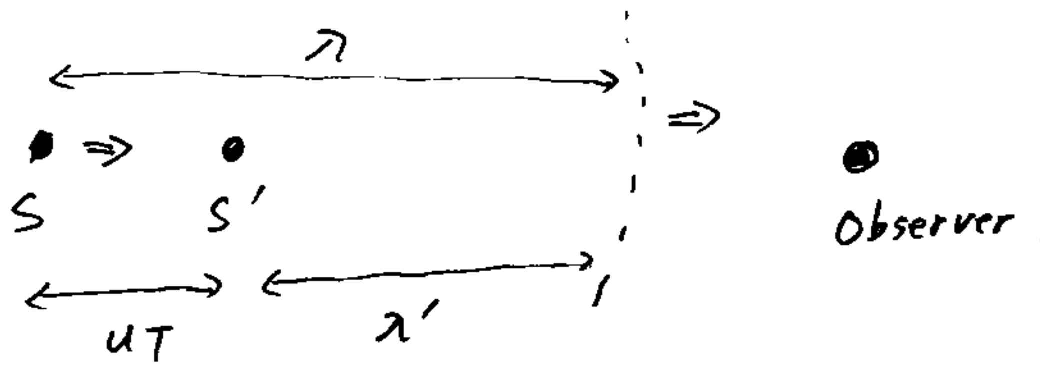
$$f' = f \qquad \begin{cases} f' \text{ — observed freq.} \\ f \text{ — original freq. generated by the source.} \end{cases}$$

②. Source approaching. observed freq. is higher.

$$f' = \frac{f}{\left(1 - \frac{u}{v}\right)} > f$$

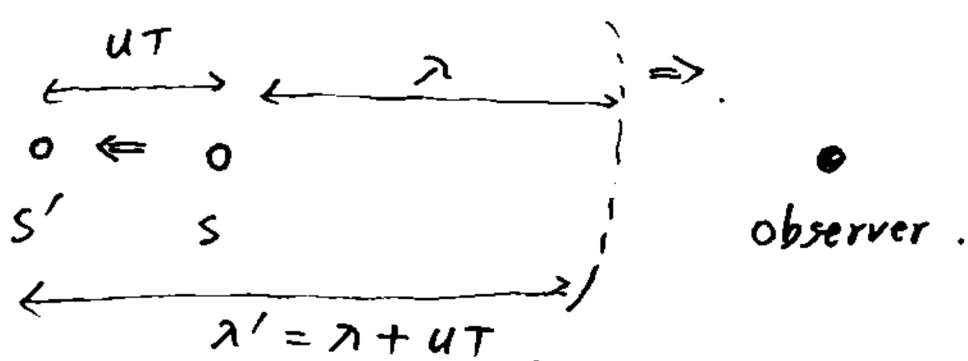
v — speed of wave.
u — speed of source.

Reason: wave length becomes shorter: $\lambda' = \lambda - uT$.



③. Source receding.

— wavelength becomes longer: $\lambda' = \lambda + uT$.

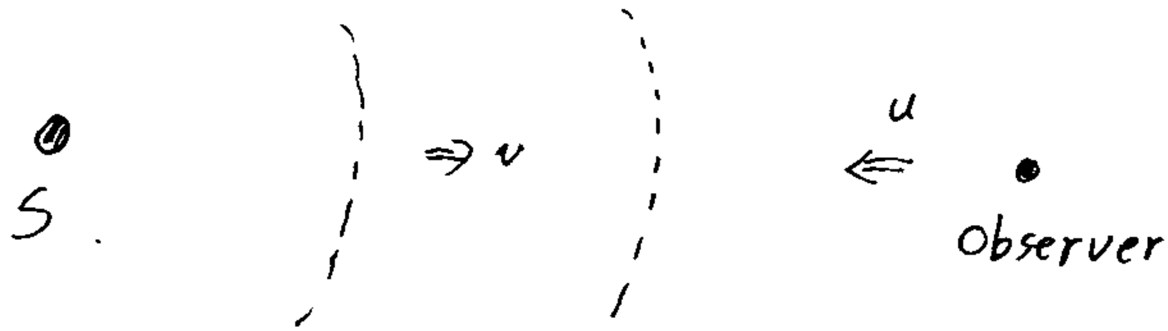


Then: $$f' = \frac{f}{\left(1 + \frac{u}{v}\right)} . \qquad f' < f .$$

The observed freq. is lower.

④ Observer approaching.

— The source doesn't move, but the observer moves towards the source.



Then, to the observer, the speed of the wave is

$$v' = v + u.$$

the observed frequency:

$$f' = \frac{v'}{\lambda} = \frac{u+v}{\lambda} = f\left(1 + \frac{u}{v}\right).$$

$f' > f$. The observed freq. is higher

⑤. observer receding at a speed of u.

The speed of wave to the observer becomes:

$$v' = v - u.$$

Then: $f' = f\left(1 - \frac{u}{v}\right) < f$. (freq. becomes lower).

⑥ General case

— When both the source and the observer are moving.

$$f' = f \left(\frac{1 \pm u_o/v}{1 \mp u_s/v} \right) \begin{array}{l} \leftarrow \text{observer.} \\ \leftarrow \text{source} \end{array}$$

Sign:

approaching : $f' > f$. (shift to higher freq)

receding: $f' < f$. (shift to lower freq.)

e.g. CAPA set 6 # 11

Double Doppler effect.

① The van is a moving observer when it receives the wave from the radar. $f' = f(1 - \frac{u}{v})$

②. Then the van becomes a moving source when it reflects the wave to the police. $f'' = f' / (1 + \frac{u}{v})$

$$\therefore \quad f'' = f \left(\frac{1 - \frac{u}{v}}{1 + \frac{u}{v}} \right)$$

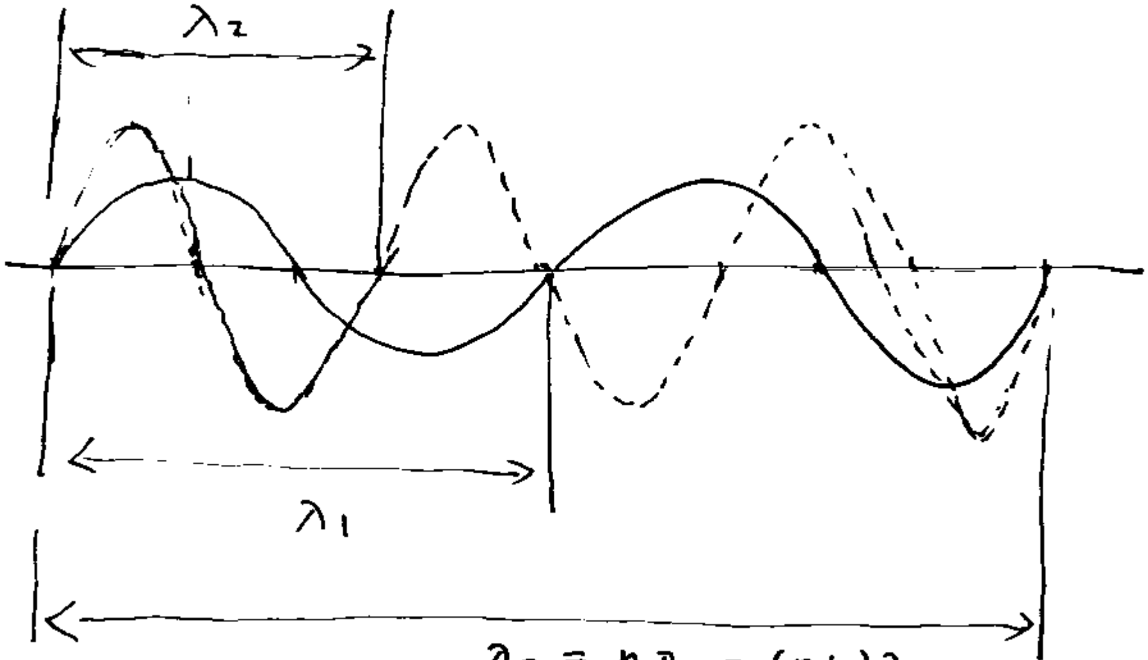
If $u \ll v$, f'' is slightly lower than f.

- Beats.

Two waves with nearly the same frequency have a low "Beat frequency".

For sound waves, the beat can be audible. i.e., the intensity varies at a low "beat frequency".

Demo : Tuning Forks.



Wavelength of the beat : (common multiple of the 2 wavelengths

$$n\lambda_1 = \lambda_B$$

$$(n+1)\lambda_2 = \lambda_B.$$

eliminate n : $$\frac{\lambda_B}{\lambda_1} = \frac{\lambda_B}{\lambda_2} - 1$$

$$\frac{1}{\lambda_B} = \frac{1}{\lambda_2} - \frac{1}{\lambda_1}.$$

$$f_B = f_2 - f_1 \qquad (\because f = \frac{v}{\lambda})$$

$\therefore$ frequency of the beat : $f_B = |f_2 - f_1|$.

~~Math derivation~~