Optics and Waves

Lecture 9

-Doppler shift
-Shock wave

Young and Freedman 16.3; 16.8; 16.9

Doppler shift https://www.youtube.com/watch?v=a3RfULw7aAY

Doppler effect (for sound)

If a wave source and receiver are moving relative to each other, the frequency detected by the receiver is different from that emitted by the source.

Two scenarios (1) moving source (2) moving observer

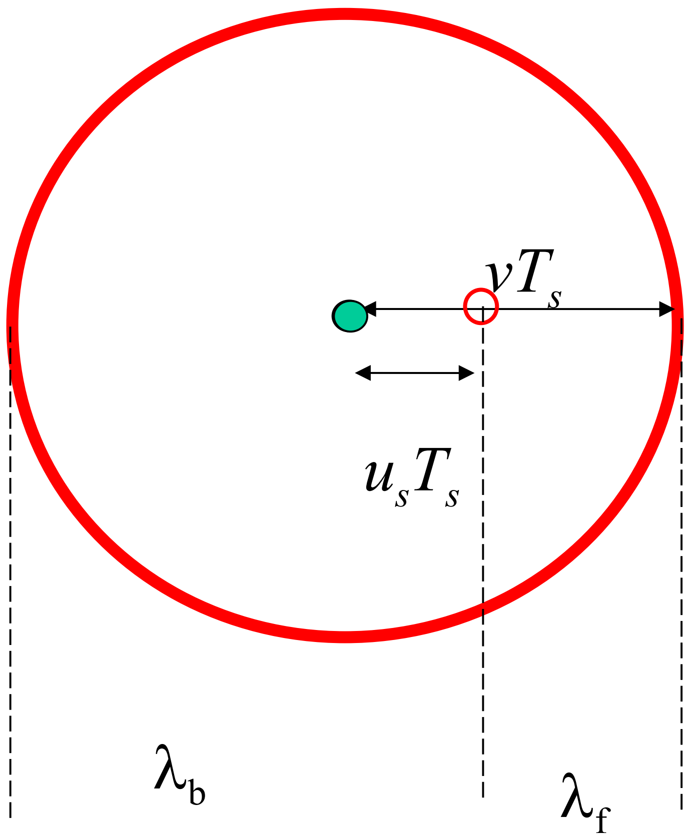
Source movingDopplehttp://www.youtube.com/watch?v=wsjO

1) moving source (receiver at rest)

Source has frequency: f_s (period $T_s=1/f_s$)

speed of source: u_s

velocity of waves in medium: v



Receiver in forward direction

$$\lambda_f = \frac{v}{f_s} - \frac{u_s}{f_s} = \frac{v-u_s}{f_s}$$

observed frequency

$$f_f = \frac{v}{\lambda_f} = \frac{v}{v-u_s} f_s$$

Receiver in backward direction

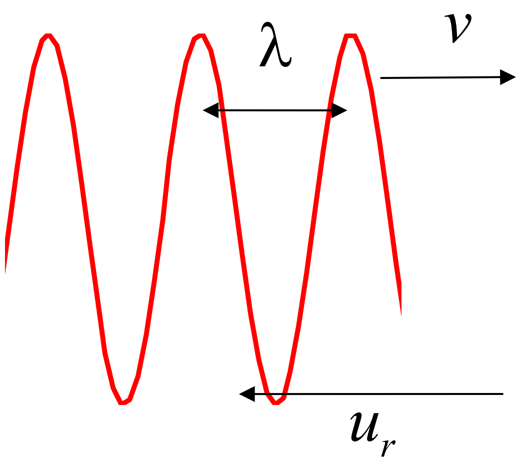
$$\lambda_b = \frac{v}{f_s} + \frac{u_s}{f_s} = \frac{v+u_s}{f_s}$$

observed frequency

$$f_b = \frac{v}{\lambda_b} = \frac{v}{v+u_s} f_s$$

Case 2) receiver moving:
If moving towards source of the wave, encounters more wave crests per second and thus higher frequency.

Speed of receiver: u_r. To the receiver, wave with wavelength λ appears to travel at $v+u_r$



$$v + u_r = \lambda f_r$$

$$f_r = \frac{v+u_r}{\lambda} = \frac{v+u_r}{\frac{v}{f_s}} = \frac{v+u_r}{v} f_s$$

If receiver moves away from source $$f_r = \frac{v-u_r}{v} f_s$$

The movement of the source or the receiver is measured relative to the medium: air.

Source moving $f_r = \frac{v}{v \pm u_s} f_s$ (− towards, + away)

Receiver moving $f_r = \frac{v \pm u_r}{v} f_s$ (+ towards, − away)

Both moving $f_r = \frac{v \pm u_r}{v \pm u_s} f_s$

Moving towards, f increase; away, f decrease.

Doppler for light (relativity):
Doppler shift in freq. depends on if source or receiver is moving relative to the medium.
For light, for which there is no medium (propagates in vac), absolute motion cannot be detected; only relative motion of source and receiver can be determined.

$$f_r = f_s\sqrt{\frac{c \pm u}{c \mp u}} = f_s\left(1 \pm \frac{u}{c}\right)^{1/2}\left(1 \mp \frac{u}{c}\right)^{-1/2}$$

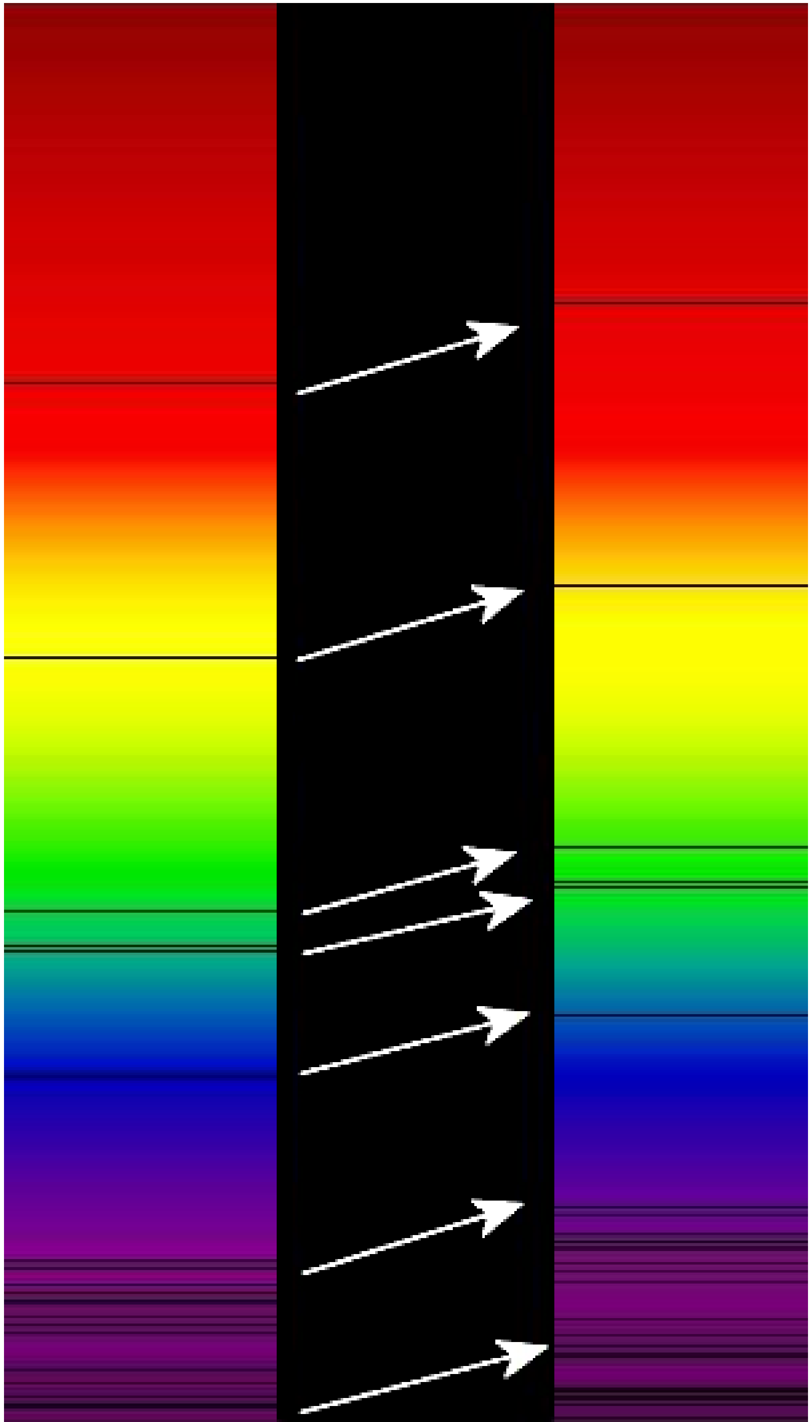
$$= f_s\left(1 \pm \frac{1}{2}\frac{u}{c}\right)\left(1 \pm \frac{1}{2}\frac{u}{c}\right) = f_s\left(1 \pm \frac{u}{c}\right)$$

ignoring terms in $\left(\frac{u}{c}\right)^2$

i.e.

$$\frac{\Delta f}{f_s} = \pm\frac{u}{c}$$

Austrian physicist Christian Doppler, who proposed it in 1842 in Prague.



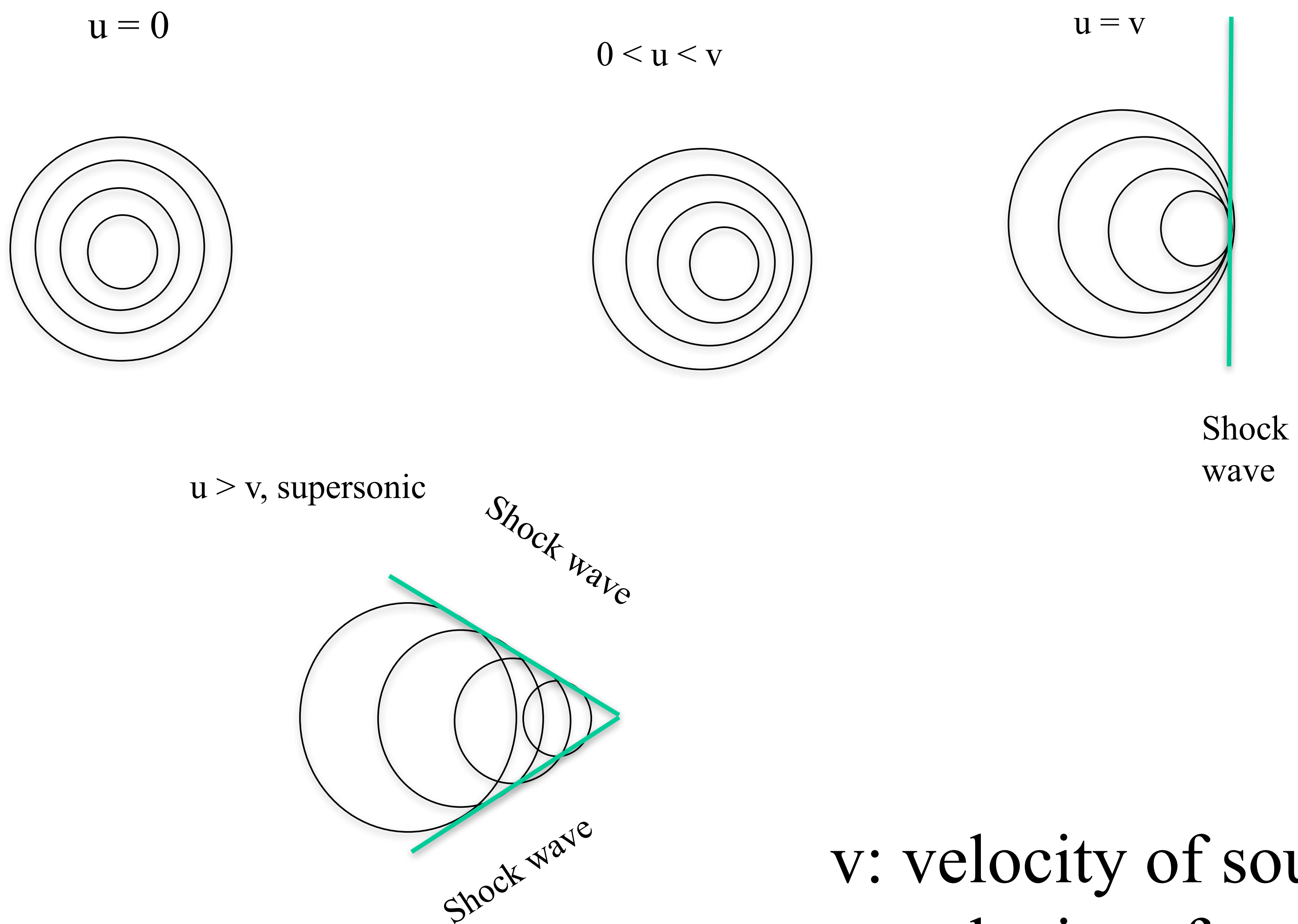
http://en.wikipedia.org/wiki/File:Redshift.png

Shock waves:

is what happens when the velocity of the source is faster than the velocity of waves in the medium

Speed boat phenomenon

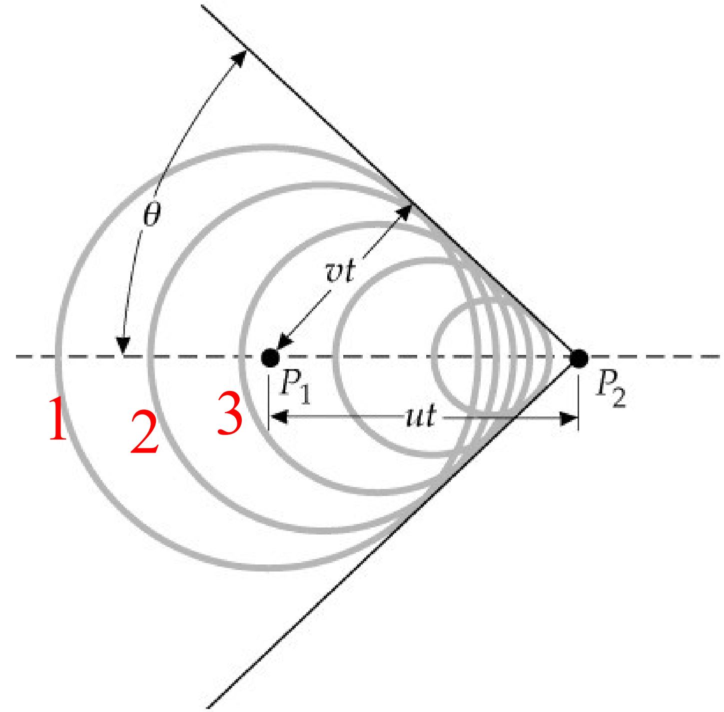
Effect of increasing source velocity:



v: velocity of sound

u: velocity of source

$$\sin\theta = \frac{vt}{ut} = \frac{v}{u}$$



Mach cone angle: θ

Mach number = u/v

Along the path of the plane, the sound waves produced later are heard first.

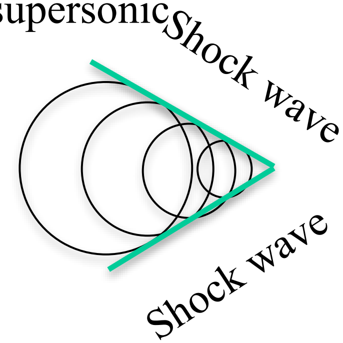
O LL E H H E LL O

Shock wave

At the back of the supersonic source, the frequency is significantly shifted:

$$f_b = \frac{v}{v+u} f_s < \frac{1}{2} f_s$$

u > v, supersonic



In front of the source, the perceived frequency turns negative?

Sonic boom[sonic boom]