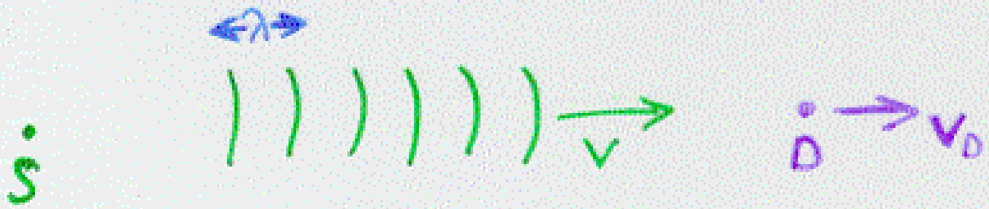
Doppler Effect for Sound: Motion Relative to Wave-carrying medium.

e.g. police sirens (+ radar guns), bat "sonar"

Two cases: source moving, detector moving
(all speeds relative to the medium e.g. air)

(1) Sound detector moving at speed V_D, stationary source:



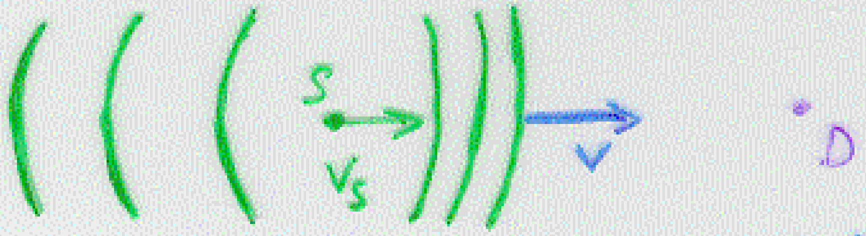
Detector "sees" same wavelength λ, but wave peaks now move at relative speed $(V - V_D)$ over detector

$$\Rightarrow \text{detected freq. } f' = \frac{(V - V_D)}{\lambda} = f\,\frac{(V - V_D)}{V}$$

For receding detector, $V_D > 0 \Rightarrow f' < f$ (lower note)
" approaching " , $V_D < 0 \Rightarrow f' > f$ (higher ")

[Remember: Moving detector ⇒ λ same, relative speed and f vary]

Doppler Effect Case ②: Moving Source, stationary detector.



(Fig 18.21)

Source emits waves at freq. f, period $T = 1/f$.

Distance between peaks ahead of source $= vT - v_S T$

$\Rightarrow$ Wavelength "compressed" to $\lambda' = (v - v_S)T = \left(\frac{v - v_S}{f}\right)$

c.f. Wavelength of sound at rest $\lambda = \frac{v}{f}$

$\Rightarrow \quad \lambda' = \frac{(v - v_S)}{v}\lambda$ $\quad < \lambda$ when source approaches
$> \lambda$ " " recedes

[Remember: Moving source has same f, but λ changes.]

New frequency of waves received at D is $f' = \frac{v}{\lambda'} = f\frac{v}{(v - v_S)}$

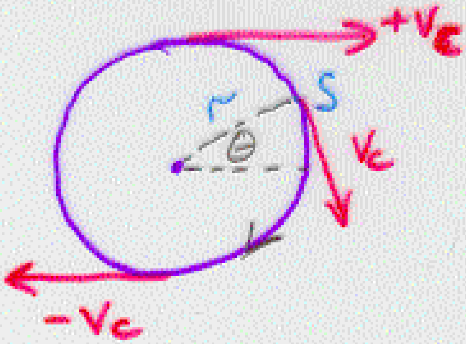
For general case (source and detector moving)

$$f' = \frac{v - v_D}{\lambda'} = \frac{(v - v_D)}{(v - v_S)} f$$

"Doppler factor"

Note: Signs of v_D, v_S work when detector is to right of source.

Example: Source moving in a circle



radius r, speed v_c

·D

Component of velocity approaching detector

$$v_s = v_c \sin\theta = v_c \sin \omega_c t$$

Where ang. freq. $\omega_c = \frac{v_c}{r} = 2\pi f_c$

$\Rightarrow$ Detector hears $f' = \frac{f\,v}{v - v_s}$

$$f' = \frac{f\,v}{v - v_c \sin\left(\frac{v_c}{r} t\right)}$$

e.g. for $f_c = 3\text{Hz}$, $r = 1\text{m}$

$\Rightarrow$ Circular speed $v_c = r\omega_c = 2\pi r f_c = 18.8\text{ m/s}$

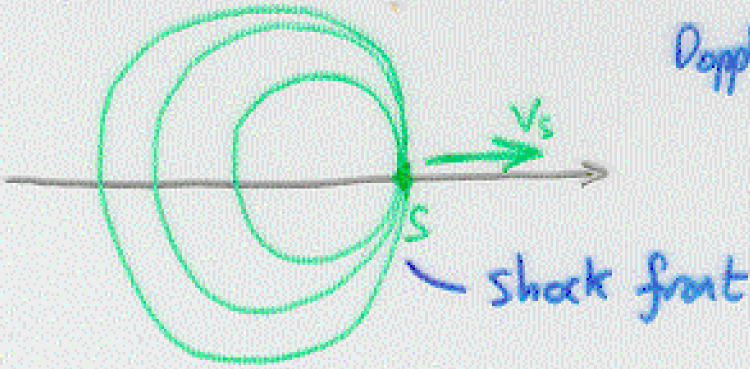
$\Rightarrow$ Doppler factor varies between

$$\frac{330\text{m/s} = v}{330 - 18.8} = 1.06 \quad \text{and} \quad \frac{330}{330 + 18.8} = 0.946$$

($f = 440\text{Hz}$ $\Rightarrow$ f' varies from 416Hz to 466 Hz)

Supersonic Motion: Shock waves

For source moving at sound speed $v_s = v$



Doppler $\Rightarrow f' = \frac{f}{0}$
$\Rightarrow \infty!$

- all wave peaks keep pace with source
  $\Rightarrow$ pile up at source - rough ride!

For $v_s > v$, wave fronts are "left behind" .....

In time t, source moves $v_s t$, wave moves vt
$2t$ $\qquad 2v_s t \qquad 2vt$

$\Rightarrow$ Wave fronts form surface of cone

$$\sin\theta = \frac{vt}{v_s t} = \frac{v}{v_s} \equiv \frac{1}{M}$$

M — Mach number

$M = 2 \Rightarrow \sin\theta = 1/2 \Rightarrow \theta = 30°$