Doppler effect

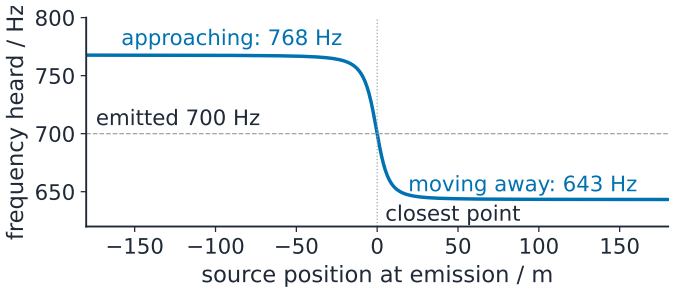
C.5 · SL and AHL

Why does a siren change its note as it passes?

Relative motion along the line of sight changes the observed frequency.

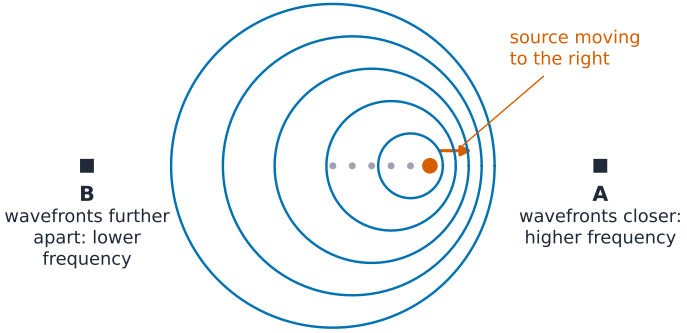
- Higher while the ambulance approaches, lower as it drives away.
- The driver hears a steady note all the time.
- This unit: wavefronts $\rightarrow$ light $\rightarrow$ spectral lines $\rightarrow$ equations.

The Doppler effect



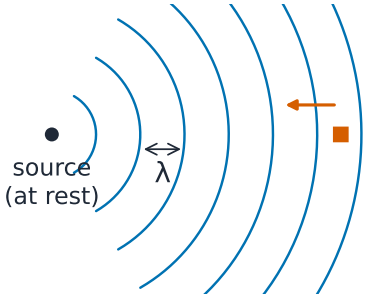
- Approach gives a higher frequency; recession gives a lower frequency.
- The first-order light shift uses radial velocity; transverse relativistic effects are outside this approximation.

A moving source



- Each circle is centred where the source was when it was emitted.
- Ahead, shorter wavelength; behind, longer wavelength; same wave speed.

A moving observer



observer moves towards the source

meets more wavefronts per second: higher frequency

- The wavelength is unchanged.
- The observer meets more wavefronts per second.

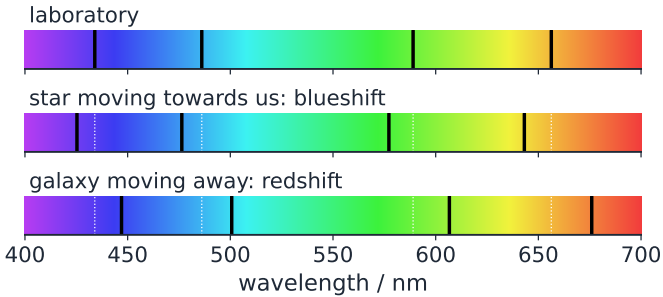
The Doppler effect for light

- 500 nm observed at 501 nm gives 6.0×10^5 m s^{-1} away.
- **Redshift** means moving away; **blueshift** means moving towards.

$$\frac{|\Delta f|}{f} \approx \frac{|\Delta \lambda|}{\lambda} \approx \frac{|v_r|}{c}$$

Low-speed Doppler model: signed frequency and wavelength changes have opposite signs.

Spectral lines shift together



- Every line moves by the same fraction of its wavelength.
- Hydrogen 656.3 nm seen at 659.0 nm means 1.2×10^6 m s^{-1} away.

What the shifts reveal

Stars

Motion towards or away from us.

Binary orbits and planets tugging them.

Galaxies

Projected rotation; correct for inclination.

Cosmological **redshift** uses an expansion model.

Check: a redshift

Your turn

An identified 600.0 nm rest line is observed at 601.2 nm in an invented low-speed Doppler model. With $c = 3.00 \times 10^8$ m/s, find radial speed and direction.

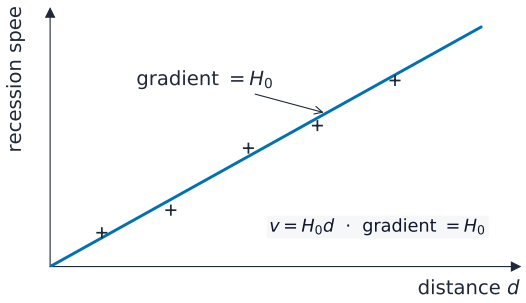
A. 2.0×10^5 m s^{-1} towards us

B. 6.0×10^5 m s^{-1} towards us

C. 6.0×10^5 m s^{-1} away from us

D. 1.2×10^6 m s^{-1} away from us

Hubble's law



Farther galaxies recede faster

A moving source of sound

- Minus when the source approaches; plus when it moves away.
- A 700 Hz siren at 30 m s^{-1} gives 768 Hz, then 643 Hz.

$$f' = f\frac{v}{v \pm u_s}$$

v is the wave speed in the medium; u_s is the source speed.

Worked example: the speed of a train

1. **Known.** 400 Hz horn heard at 420 Hz; source approaching an observer stationary in air; sound speed 340 m/s.
2. **Rearrange.** $340 - u_s = 340 \times 400/420 = 323.8$.
3. **Solve.** $u_s = 340 - 323.8$.

Decision

$u_s = 16$ m s^{-1}

A moving observer of sound

- Plus when the observer approaches; minus when moving away.
- At 20 m s^{-1} past a 500 Hz alarm, 529 Hz then 471 Hz.

$$f' = f\frac{v \pm u_o}{v}$$

Decide first whether the frequency rises or falls.

Exam tips

> Identify the lines, calculate the signed shift and state the physical model.

- The source still emits the same frequency.
- A moving source changes the wavelength; a moving observer does not.
- Use radial velocity for the low-speed light approximation; a zero radial shift does not give the full velocity.

Check yourself

Try these

In a low-speed Doppler model, a 486.1 nm rest line is seen at 490.0 nm. Find radial velocity using $c = 3.00 \times 10^8$ m/s.

Explain how Doppler shifts reveal the rotation of a galaxy.

HL. A 400 Hz horn approaches an observer stationary in air and is heard at 420 Hz. Sound speed is 340 m/s. Find source speed.