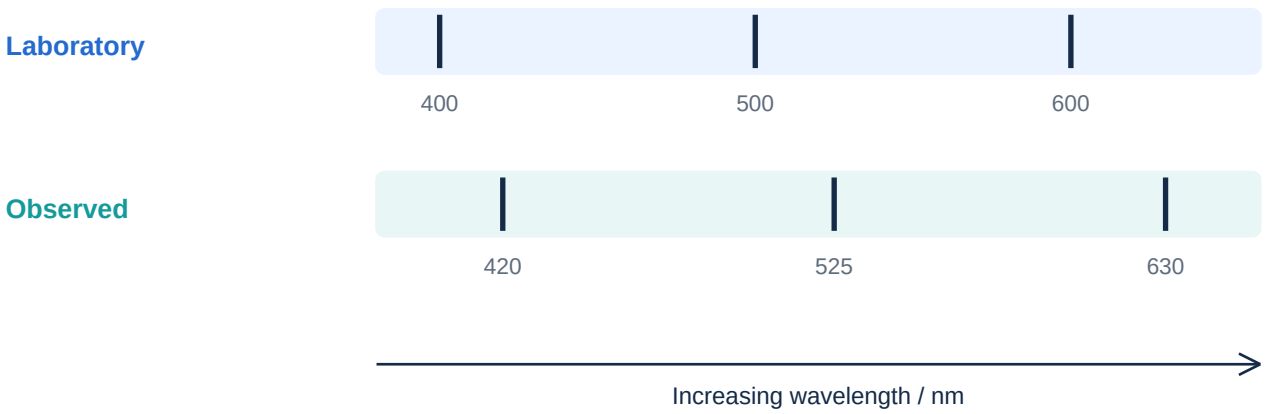
LESSON 5.4.3

Redshift, Hubble's Law and the Expanding Universe

Identify a known spectral line, measure its wavelength shift and compare the recession of galaxies with their distances. Light carries evidence about cosmic expansion.

MATCH THE PATTERN, NOT JUST ONE COLOUR



Illustrative lines: every observed wavelength is 1.05 times its rest value.

$$z = \frac{\lambda_{obs} - \lambda_{rest}}{\lambda_{rest}} = \frac{\Delta\lambda}{\lambda_{rest}} \approx \frac{v}{c}$$

Redshift: $z > 0$, longer wavelength, lower frequency. Blueshift: $z < 0$, shorter wavelength, higher frequency. For a Doppler shift, v is the radial velocity, positive for recession; $v \approx cz$ requires speeds much less than c.

WORKED LOW-REDSHIFT EXAMPLE

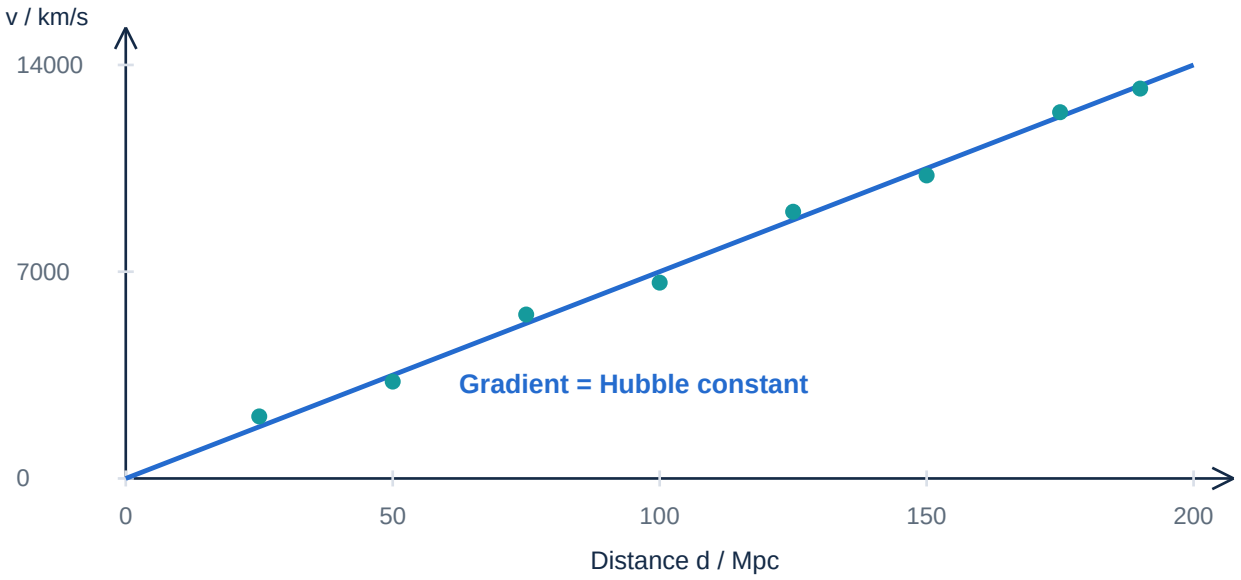
$$z = \frac{505 - 500}{500} = 0.0100 \qquad v \approx 3000 \text{ km/s}$$

Use the same wavelength units in the ratio. Here c = 300 000 km/s. For a small redshift, z also approximates the fractional decrease in frequency: (rest frequency - observed frequency) / rest frequency.

1 More distant galaxies recede faster

On large scales, galaxy recession speed increases with distance. Hubble's law describes the present expansion; local gravitational motions add scatter.

ILLUSTRATIVE LOW-REDSHIFT DATA, NOT OBSERVATIONS



$$v = H_0 d \qquad H_0 = \frac{\Delta v}{\Delta d}$$

Use the gradient of a best-fit line, not one scattered data point. Distance must be measured independently, for example using calibrated standard candles. One megaparsec (Mpc) is one million parsecs.

CONTINUE THE EXAMPLE: v = 3000 km/s

$$d = \frac{v}{H_0} = \frac{3000}{70} = 42.9 \text{ Mpc}$$

The example uses 70 km/s/Mpc as an illustrative Hubble constant, not a claim of an exact measured value. Keeping v in km/s gives d in Mpc.

WHAT DOES EXPANSION MEAN?

On cosmic scales, separations between unbound galaxies grow and light wavelengths stretch during travel. This is not an explosion from Earth into empty space. Bound systems need not expand; some nearby galaxies approach us.

Expansion and the cosmic microwave background support a hot, dense early universe.

2 Age estimates and the universe's fate

Running today's recession backwards at unchanged speed gives a characteristic timescale. It is an estimate, not a complete history of cosmic expansion.

$$t \approx \frac{d}{v} = \frac{1}{H_0}$$

Convert the Hubble constant to reciprocal seconds before taking its reciprocal. Use 1 Mpc = 3.086×10^{22} m and 31.56 million seconds per year in the calculation below.

$$H_0 = \frac{70 \times 10^3}{3.086 \times 10^{22}} = 2.27 \times 10^{-18}\ s^{-1}$$

$$t \approx 4.41 \times 10^{17}\ s \approx 14.0 \text{ billion years}$$

A larger Hubble constant gives a smaller reciprocal timescale. The actual age depends on how expansion changed with time. Distance calibration, measurement errors and cosmological assumptions affect estimates.

DARK MATTER: EXTRA GRAVITY

Inferred from gravitational effects, including galaxy motions and gravitational lensing. It does not emit or absorb light like ordinary luminous matter. Its microscopic identity remains unknown.

DARK ENERGY: ACCELERATION

Distant supernova measurements support accelerated expansion. Dark energy is the name for the component used to explain this in the standard cosmological model; its physical nature is unresolved.

WHY THE FUTURE DEPENDS ON THE MODEL

In a simple matter-only model, enough density can halt expansion and cause recollapse. At or below the critical density, expansion continues indefinitely. Dark matter contributes to this gravitating density.

Dark energy changes that prediction. With a positive cosmological constant, late-time accelerated expansion can continue. Present expansion alone does not prove a unique fate: the matter content and dark energy's behaviour must also be known.

Curriculum: Pearson IAL Physics pp. 36-37, points 169-171.

Reading: Doppler effect | Expanding universe | Dark matter | Dark energy

NASA: the early universe. Next: 6.1.1 Planning investigations from Units 4 and 5.