

## Unit 5: Thermodynamics, Radiation, Oscillations and Cosmology

WPH15 · Issue 3 · requirements 125–171 · sheets 5.1–5.9

## From an ice pack to a star

- Energy links molecules, nuclei, oscillators and stars.
- WPH15: requirements 125–171; use Units 1, 2 and 4.
- Train on sheets 5.1–5.9, then attempt the matching authentic sets.

## Temperature is not internal energy

### Temperature

Relates to average random molecular kinetic energy.

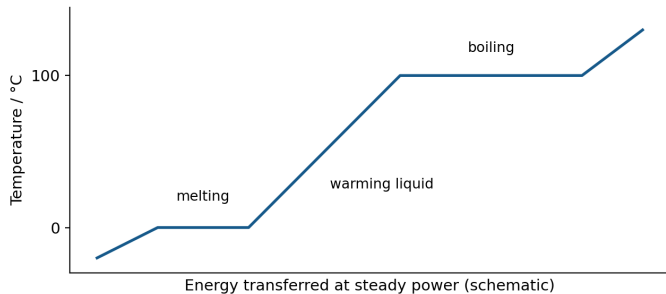
A small and a large sample can have the same temperature.

### Internal energy

Total random kinetic and intermolecular potential energy.

Depends on amount and state.  
Whole-object motion is separate.

## Read the heating curve



- Sloping section:  $\Delta E = mc\Delta\theta$ .
- Flat phase change:  $\Delta E = L\Delta m$ .

## Your turn: warm, then melt

### An ice pack absorbs energy

A 0.40 kg block of ice starts at  $-10\text{ }^{\circ}\text{C}$  and finishes as water at  $0\text{ }^{\circ}\text{C}$ .

$$c_{\text{ice}} = 2100\text{ J kg}^{-1}\text{ K}^{-1} \text{ and } L_f = 3.4 \times 10^5\text{ J kg}^{-1}.$$

Calculate the warming energy, melting energy and total energy. Explain why there are two stages.

## Two stages require two equations

1 **Warm**  $E_{\text{warm}} = mc\Delta\theta = (0.40 \text{ kg})(2100 \text{ J kg}^{-1} \text{ K}^{-1})(10 \text{ K}) = 8400 \text{ J}$

2 **Melt**  $E_{\text{melt}} = mL_f = (0.40 \text{ kg})(3.4 \times 10^5 \text{ J/kg}) = 136000 \text{ J}$

3 **Add**  $E_{\text{total}} = E_{\text{warm}} + E_{\text{melt}} = (8400 + 136000) \text{ J} = 144400 \text{ J}$

## Input energy is not all useful energy

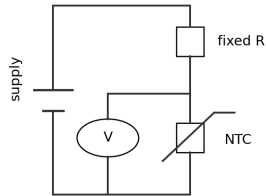
| Quantity                                                    | Calculation                                                             |
|-------------------------------------------------------------|-------------------------------------------------------------------------|
| Input: 1000 W for 600 s                                     | $E_{\text{in}} = Pt = (1000 \text{ W})(600 \text{ s}) = 600 \text{ kJ}$ |
| Evaporate 0.20 kg;<br>$L_v = 2.26 \times 10^6 \text{ J/kg}$ | $E_{\text{useful}} = mL_v = 452 \text{ kJ}$                             |
| Efficiency                                                  | $\eta = E_{\text{useful}}/E_{\text{in}} = 452/600 = 75.3\%$             |

### Use the evidence

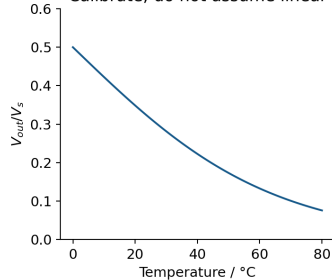
For a kettle claim, compare all loads and all losses over the same time interval.

## CP12: calibrate the actual divider

Output across lower thermistor



Calibrate; do not assume linear



- Measure output across the lower NTC thermistor.
- Warm bath: resistance falls, so this output falls.

## CP12–13: control what the equations assume

| Method                                | Measurement and control                                                                           |
|---------------------------------------|---------------------------------------------------------------------------------------------------|
| CP12: calibrate thermistor            | Stirred bath + reference thermometer; wait for equilibrium; fixed supply; repeat warming/cooling. |
| CP13: latent heat                     | Measure electrical power, time and mass change during steady phase change.                        |
| Correct approximately constant losses | $L = (P_2 - P_1)/(\dot{m}_2 - \dot{m}_1)$ at comparable phase-change temperature.                 |

## Use the evidence

The subtraction is justified by the constant-loss assumption, not by algebra alone.

# Ideal gas: temperature must be absolute

## Model and units

Negligible particle volume; elastic collisions; no other intermolecular forces.

$pV = Nk_B T$ : pascals, cubic metres, kelvin;  $N$  counts molecules.

## Choose the constraint

Fixed  $N, V$ :  $p/T$  is constant.

Fixed  $N, T$ :  $pV$  is constant. Use absolute pressure; convert  $^{\circ}\text{C}$  to K.

## Your turn: a rigid gas vessel

### A sealed vessel warms

Initially  $p = 1.0 \times 10^5$  Pa,  $V = 2.0 \times 10^{-3}$  m<sup>3</sup> and  $T = 300$  K. The final temperature is 360 K.

Use  $k_B = 1.38 \times 10^{-23}$  J K<sup>-1</sup>. Find the molecule number and final pressure.

Identify the quantities that remain fixed before choosing the equations.

## Keep the molecule number fixed

1 **Count**  $N = pV/(k_B T) = (200 \text{ J})/[(1.38 \times 10^{-23} \text{ J/K})(300 \text{ K})] = 4.83 \times 10^{22}$

2 **Warm**  $p_2 = p_1 T_2/T_1 = (1.0 \times 10^5 \text{ Pa})(360 \text{ K})/(300 \text{ K}) = 1.2 \times 10^5 \text{ Pa}$

## Derive pressure from wall collisions

- 1 Collision** A molecule in a cube of side  $l$  transfers  $\Delta p_x = 2m_0 c_x$  to a wall.
- 2 Return** Time between impacts on that same wall:  $\Delta t = 2l/c_x$ .
- 3 Force**  $F = \Delta p_x / \Delta t = m_0 c_x^2 / l$ .
- 4 Pressure** Sum and divide by wall area:  $p = Nm_0 \langle c_x^2 \rangle / l^3$ .

## Three directions give the factor of three

- 1 **Isotropy**  $\langle c^2 \rangle = 3\langle c_x^2 \rangle$  and  $V = \beta$ .
- 2 **Pressure**  $pV = \frac{1}{3}Nm_0\langle c^2 \rangle$ .
- 3 **Compare** Set  $\frac{1}{3}Nm_0\langle c^2 \rangle = Nk_B T$  and cancel  $N$ .
- 4 **Energy**  $\frac{1}{2}m_0\langle c^2 \rangle = \frac{3}{2}k_B T$ .

## Same temperature does not mean same speed

### Same temperature

Mean translational energy:  $\frac{3}{2}k_B T$ .

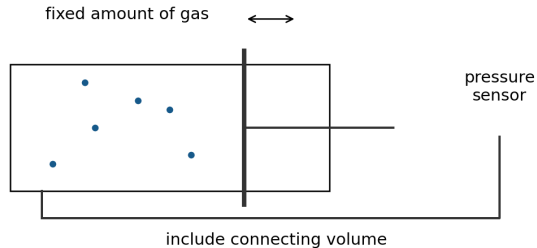
Different species therefore have equal mean translational kinetic energy.

### Different mass

$$c_{\text{rms}} = \sqrt{3k_B T / m_0}.$$

At equal temperature, double RMS speed means one-quarter molecular mass.

## CP14: keep temperature and gas amount fixed



- Compress slowly; wait for thermal equilibrium.
- Use absolute pressure and include tube dead volume.

## Binding energy accounts for a mass difference

- 1 **Count** A nucleus contains  $Z$  protons and  $A - Z$  neutrons.
- 2 **Compare**  $\Delta m = Zm_p + (A - Z)m_n - m_{\text{nucleus}}$ .
- 3 **Separate**  $E_b = \Delta mc_0^2$ : energy needed to produce free nucleons.
- 4 **Check** Use consistent nuclear/atomic masses and units; account for electrons consistently.

## Your turn: energy per nucleon

Separate a nucleus into free nucleons

A nucleus with four nucleons has mass deficit  $0.030 \text{ u}$ .

Use  $1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$ ,  $c_0 = 3.00 \times 10^8 \text{ m/s}$  and  $1 \text{ MeV} = 1.60 \times 10^{-13} \text{ J}$ .

Find its total binding energy in joules, then its binding energy per nucleon in MeV.

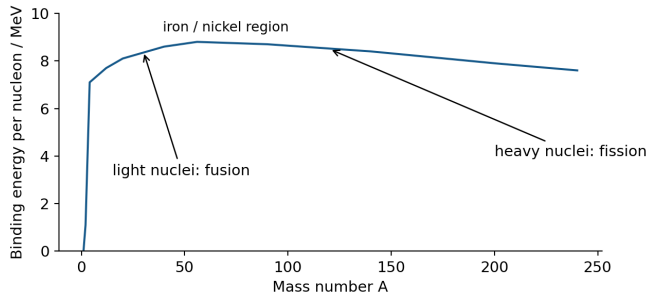
## Convert mass, energy and nucleon count

1 **Mass**  $\Delta m = (0.030 \text{ u})(1.66 \times 10^{-27} \text{ kg/u}) = 4.98 \times 10^{-29} \text{ kg}$

2 **Energy**  $E_b = \Delta mc_0^2 = (4.98 \times 10^{-29} \text{ kg})(3.00 \times 10^8 \text{ m/s})^2 = 4.48 \times 10^{-12} \text{ J}$

3 **Per nucleon**  $E_b/A = (4.48 \times 10^{-12} \text{ J})/(4 \times 1.60 \times 10^{-13} \text{ J/MeV}) = 7.00 \text{ MeV}$

## Fusion and fission can both release energy



- Products can have greater binding energy per nucleon.
- Compare total reactant and product masses for the released energy.

## Explain why fusion needs extreme conditions

### High temperature

Positive nuclei repel electrically.

Greater kinetic energy permits closer approach despite repulsion.

### Density and confinement

More close encounters per unit time.

Sustain enough reactions and retain energy. These roles differ from overcoming repulsion.

## Choose radiation by interaction

| Radiation | Interaction                    | Useful interpretation                                              |
|-----------|--------------------------------|--------------------------------------------------------------------|
| Alpha     | Strong ionisation; short range | Thick track: ionisation. Straighter track: relatively large mass.  |
| Beta      | Intermediate penetration       | Partial paper transmission enables thickness monitoring.           |
| Gamma     | Weak ionisation; penetrating   | Lead reduces intensity progressively; no sharp stopping thickness. |

## Nuclear equations conserve both rows

- 1 **Process** Beta-minus converts a neutron to a proton, electron and electron antineutrino.
- 2 **Example**  ${}^{14}_6\text{C} \rightarrow {}^{14}_7\text{N} + {}^0_{-1}\text{e} + {}^0_0\bar{\nu}_e$
- 3 **Check** Nucleon number:  $14 = 14 + 0 + 0$ . Charge number:  $6 = 7 - 1 + 0$ .
- 4 **Distinguish** Alpha lowers  $A$  by 4 and  $Z$  by 2; gamma changes neither. Energy and momentum still conserve.

## Your turn: move a gamma detector

Predict the actual detector reading

At distance  $r$  the detector records  $62 \text{ min}^{-1}$ , including a background rate of  $14 \text{ min}^{-1}$ .

The detector moves to  $2r$ . Assume a small isotropic gamma source and negligible absorption.

Calculate the new total reading. Explain which contribution follows the inverse-square law.

## Subtract, scale, then restore background

- 1 **Correct**  $R_{s,1} = R_1 - R_b = (62 - 14) \text{ min}^{-1} = 48 \text{ min}^{-1}$
- 2 **Distance**  $R_{s,2} = R_{s,1}(r/2r)^2 = (48 \text{ min}^{-1})/4 = 12 \text{ min}^{-1}$
- 3 **Measured**  $R_2 = R_{s,2} + R_b = (12 + 14) \text{ min}^{-1} = 26 \text{ min}^{-1}$

## Random nuclei, predictable populations

### One nucleus

Spontaneous: no external trigger.

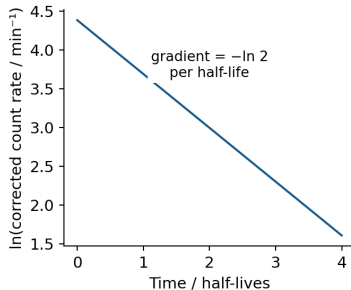
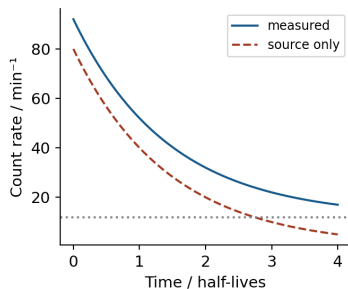
Random: its exact decay time is unpredictable. Decay constant  $\lambda$  is probability per unit time.

### A large population

$$N = N_0 e^{-\lambda t}; A = \lambda N.$$

Activity is decays per second in becquerels. Statistical predictability does not fix individual decay times.

# Derive half-life and the log gradient



- At one half-life:  $1/2 = e^{-\lambda t_{1/2}}$ .
- $\lambda = \ln 2 / t_{1/2}$ ;  $\ln(A/A_0) = -\lambda t$ .

## A fraction inside the logarithm

- 1 **Given** Half-life 3.0 years; target activity is 2.0% of its initial value.
- 2 **Model**  $A/A_0 = e^{-\lambda t}$  and  $\lambda = \ln 2/t_{1/2}$ .
- 3 **Constant**  $\lambda = \ln 2/(3.0 \text{ yr}) = 0.231 \text{ yr}^{-1}$ .
- 4 **Solve**  $t = -\ln(A/A_0)/\lambda = -\ln(0.020)/(0.231 \text{ yr}^{-1}) = 16.9 \text{ yr}$ .

### Decision

Use 0.020, not 2.0. For radioactive power, use  $P = AE_{\text{decay}}$  with energy in joules.

## CP15: attenuation is a thickness law

| Action                                                | Why it matters                                                                                |
|-------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Fix geometry and count time                           | Source contribution must be comparable across thicknesses.                                    |
| Measure and subtract background                       | Background does not follow the absorber transmission law.                                     |
| Repeat; plot log corrected rate versus lead thickness | Test exponential attenuation. Avoid near-background readings with large relative uncertainty. |

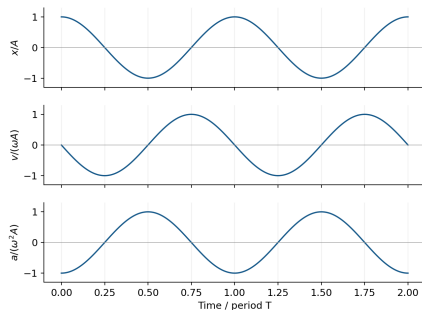
## Use the evidence

Three half-value thicknesses transmit  $1/8$ . Follow supervised source handling and shielding.

## SHM needs a restoring proportional acceleration

- 1 **Define**  $x$  is displacement from the fixed loaded equilibrium position.
- 2 **Force** For the spring resultant,  $F = -k_s x$ ; weight is already balanced at equilibrium.
- 3 **Newton**  $ma = -k_s x$ , hence  $a = -(k_s/m)x$ .
- 4 **Identify** Compare with  $a = -\omega^2 x$ :  $\omega^2 = k_s/m$ . Repetition alone is insufficient.

## Read displacement, velocity and acceleration together



- Release from  $+A_0$ :  $x = A_0 \cos \omega t$ .
- $v = -A_0 \omega \sin \omega t$ ;  $a = -A_0 \omega^2 \cos \omega t$ .

## Your turn: maxima from a graph

### Connect numerical maxima to positions

A simple harmonic oscillator has amplitude  $A_0 = 0.030$  m and period  $T = 0.50$  s.

Find angular frequency, maximum speed and maximum acceleration magnitude.

State the position where each maximum occurs and explain why they differ.

## Speed and acceleration peak at different positions

- 1 **Angular rate**  $\omega = 2\pi/T = 2\pi/(0.50 \text{ s}) = 12.6 \text{ rad/s}$
- 2 **Speed**  $v_{\text{max}} = A_0\omega = (0.030 \text{ m})(12.57 \text{ s}^{-1}) = 0.377 \text{ m/s}$
- 3 **Acceleration**  $|a|_{\text{max}} = A_0\omega^2 = (0.030 \text{ m})(12.57 \text{ s}^{-1})^2 = 4.74 \text{ m/s}^2$

## Period and energy test different properties

| Relationship                                                                    | Interpretation                                                   |
|---------------------------------------------------------------------------------|------------------------------------------------------------------|
| Spring: $T = 2\pi\sqrt{m/k_s}$                                                  | Period depends on mass and stiffness.                            |
| Small-angle pendulum: $T = 2\pi\sqrt{l/g}$                                      | State the small-angle condition.                                 |
| $E_{\text{total}} = \frac{1}{2}k_s A_0^2$ ; $E_k = \frac{1}{2}k_s(A_0^2 - x^2)$ | Kinetic energy versus displacement is a downward parabola.       |
| $a$ - $x$ gradient $= -\omega^2$                                                | Take the square root of the negative gradient to find $\omega$ . |

## CP16: calibrate before finding unknown mass

- 1 **Measure** Vary drive frequency to find resonance for several known masses.
- 2 **Transform**  $T = 1/f$ ; plot  $T^2$  against known mass.
- 3 **Calibrate**  $T^2 = 4\pi^2 m/k_s$ : use the fitted relationship to infer unknown mass.
- 4 **Evaluate** Apparatus effective mass may produce an intercept. Repeat and avoid excessively large amplitudes.

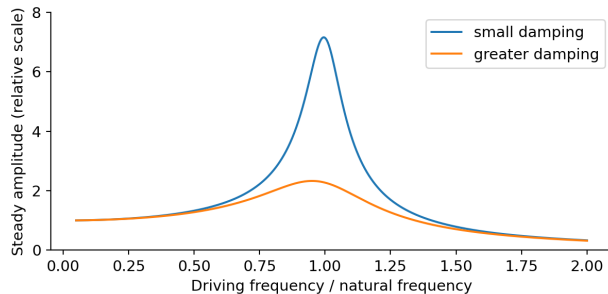
## Separate free, forced and damped oscillations

| Term               | Physical meaning                                                  |
|--------------------|-------------------------------------------------------------------|
| Free oscillation   | After release, motion occurs at a natural frequency.              |
| Forced oscillation | A periodic external force drives the motion.                      |
| Damping            | Oscillation energy transfers to other stores.                     |
| Resonance          | Large response near a natural frequency under comparable driving. |

### Use the evidence

One oscillator can be forced and damped at the same time.

## Damping changes the resonance response



- More damping usually lowers and broadens the peak.
- Compare curves at the same driving frequency.

## Your turn: explain the bridge damper

### Write a linked explanation

People walking apply periodic forces to a bridge. Under some conditions its motion grows dangerously large.

Explain the role of driving frequency, natural frequency and energy transfer.

Explain how a damper limits the response. Use cause-and-effect sentences, not a list of terms.

## A linked explanation earns its conclusion

People supply a periodic driving force.



Drive near a natural frequency → efficient energy transfer → larger amplitude.

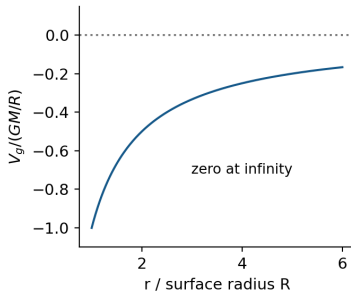
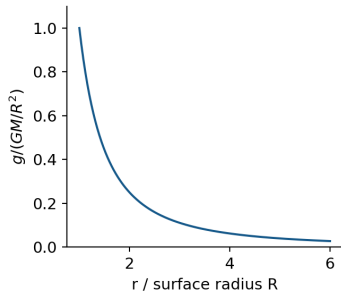


Damper opposes motion and does work  
→ energy transfers to thermal stores.



For comparable driving, less oscillation energy means a smaller steady amplitude.

## Gravity: strength and potential are different



- Field strength:  $g = GM/r^2$ , directed inward.
- Potential:  $V_{\text{grav}} = -GM/r$ , zero at infinity.

## Gravity and electricity: compare the interaction

### Gravity

Acts on mass; attraction in this model.

$F = GMm/r^2$ ; direction towards the source mass.

### Electricity

Acts on charge; attraction or repulsion.

Field direction is the force on positive test charge. A negative charge experiences the opposite force.

## Your turn: signed satellite energy change

Does the satellite gain or lose potential energy?

A 1000 kg satellite moves from  $r_1 = 6.4 \times 10^6$  m to  $r_2 = 1.28 \times 10^7$  m around a mass  $M = 6.0 \times 10^{24}$  kg.

Use  $G = 6.67 \times 10^{-11}$  N m<sup>2</sup> kg<sup>-2</sup>. Calculate final minus initial gravitational potential energy.

Predict the sign first. Explain why constant surface  $g$  is unsuitable.

## Outward motion increases signed GPE

- 1 Model**  $\Delta E = E_2 - E_1 = GMm(1/r_1 - 1/r_2)$
- 2 Substitute**  $\Delta E = (6.67 \times 10^{-11} \text{ N m}^2/\text{kg}^2)(6.0 \times 10^{24} \text{ kg})(1000 \text{ kg})[1/(6.4 \times 10^6 \text{ m}) - 1/(1.28 \times 10^7 \text{ m})]$
- 3 Result**  $\Delta E = E_2 - E_1 = +3.13 \times 10^{10} \text{ J}$

## Derive the circular-orbit relation

- 1 **Inward resultant** Gravity itself supplies centripetal force:  $GMm/r^2 = mv^2/r$ .
- 2 **Cancel mass**  $v = \sqrt{GM/r}$ , the orbiting mass does not set the ideal orbit speed.
- 3 **Period**  $T = 2\pi r/v = 2\pi\sqrt{r^3/(GM)}$ .
- 4 **Infer central mass**  $M = 4\pi^2 r^3/(GT^2)$ . Use centre-to-centre radius, not altitude or diameter.

## A matching period is not enough

### Necessary conditions

Circular equatorial orbit.

Same rotational direction and angular velocity as the planet.

### Calculate the radius

$$r = (GMT^2/4\pi^2)^{1/3}.$$

Reference values give  $4.23 \times 10^7$  m.

Subtract planet radius only when asked for altitude.

## A spectrum connects temperature and emitted power

### Wavelength spectrum

Hotter black body: shorter wavelength peak and more total emission.

$$\lambda_{\max} T = 2.898 \times 10^{-3} \text{ m K.}$$

### Check the plotted quantity

The stated Wien constant describes a spectrum per unit wavelength.

A frequency-density peak cannot generally be converted to that peak by  $\lambda = c_0/f$ .

## Two spherical areas serve different purposes

### Emitting surface

Stellar radius  $R$  sets surface area  $4\pi R^2$ .

Luminosity  $L_{\star} = 4\pi R^2 \sigma T^4$  is total power in watts.

### Receiving sphere

Observer distance  $d$  sets sphere area  $4\pi d^2$ .

Intensity  $I = L_{\star}/(4\pi d^2)$  is received power per area.

## Your turn: from colour to received intensity

Follow energy from the star to the observer

The wavelength spectrum peaks at 580 nm. Stellar radius is  $7.0 \times 10^8$  m; observer distance is  $1.5 \times 10^{11}$  m.

Use  $b = 2.898 \times 10^{-3}$  mK and  $\sigma = 5.67 \times 10^{-8}$  W m<sup>-2</sup> K<sup>-4</sup>.

Find temperature, luminosity and received intensity. Name the two different spherical areas.

Use the emitting area before the receiving area

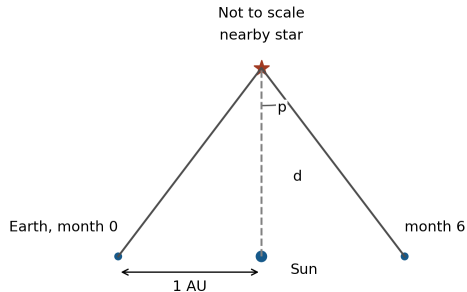
**1 Temperature**

$$T = b/\lambda_{\max} = (2.898 \times 10^{-3} \text{ m K})/(580 \times 10^{-9} \text{ m}) = 4.997 \times 10^3 \text{ K}$$

**2 Emission**  $L_{\star} = 4\pi R^2 \sigma T^4 = 2.18 \times 10^{26} \text{ W}$

**3 Reception**  $I = L_{\star}/(4\pi d^2) = (2.18 \times 10^{26} \text{ W})/[4\pi(1.5 \times 10^{11} \text{ m})^2] = 770 \text{ W/m}^2$

## Parallax uses half the six-month shift



- Baseline between observations: two Earth-orbit radii.
- $p$  is half the total angular shift;  $d_{\text{pc}} = 1/p_{\text{arcsec}}$ .

## Standard candles extend the distance ladder

### Parallax

Measure angular shift relative to background stars.

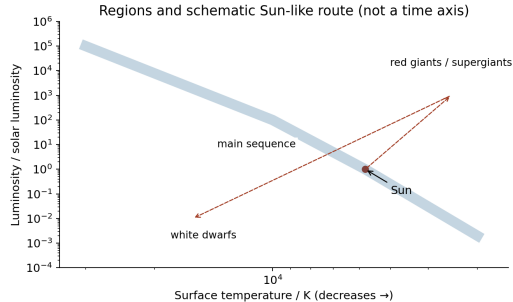
At large distance, angular resolution limits the method even if the star remains visible.

### Standard candle

Known luminosity + measured intensity:  
 $d = \sqrt{L_{\star}/(4\pi I)}$ .

Cepheid period gives calibrated luminosity. Average periods, read log axes and convert solar units.

# Read the HR axes before naming a star



- Temperature usually decreases to the right; luminosity increases upward.
- Red giant: cool and luminous; white dwarf: hot and faint.

## Your turn: explain the Sun-like route

Explain a life cycle, not just its stage names

A Sun-like star has used most of its core hydrogen. Explain the next changes in its core and outer layers.

Connect fuel depletion, contraction, temperature and fusion to the red-giant stage.

Name its remnant and explain why a massive star can have a different outcome.

## Fuel supply and consumption rate both matter

Core hydrogen declines → core fusion weakens.



Gravity contracts and heats the core; shell burning and later helium fusion accompany giant expansion.

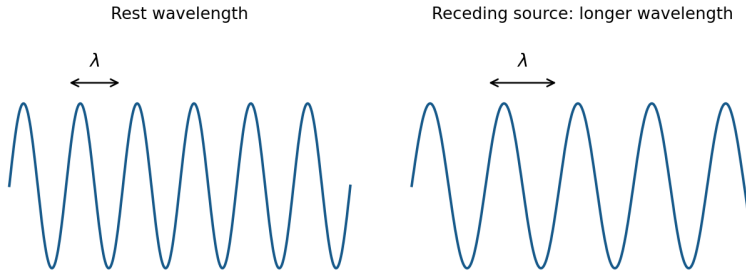


Sun-like star loses outer layers → white dwarf without sustained fusion.



Massive stars burn faster; later collapse/supernova can leave a neutron star or black hole.

## Doppler shift needs line-of-sight motion



- Recession: longer observed wavelength and lower frequency.
- Approach: shorter wavelength and higher frequency.

## Your turn: one line shifts from 500 to 505 nm

### Measure motion using the same spectral line

A line has rest wavelength 500 nm and observed wavelength 505 nm. Use  $c_0 = 3.00 \times 10^8$  m/s.

Calculate redshift and approximate line-of-sight speed. Interpret the sign.

State the low-speed assumption. Predict whether the observed frequency is higher or lower.

## Keep the wavelength and frequency signs consistent

- 1 Identify** The same line shifts from rest 500 nm to observed 505 nm.
- 2 Redshift**  $z = (\lambda_{\text{obs}} - \lambda_{\text{rest}})/\lambda_{\text{rest}} = (505 - 500)/500 = 0.010$ .
- 3 Speed**  $v \approx zc_0 = 0.010(3.00 \times 10^8 \text{ m/s}) = 3.00 \times 10^6 \text{ m/s}$ , receding.
- 4 Frequency** Observed frequency is lower, so  $(f_{\text{obs}} - f_{\text{rest}})/f_{\text{rest}}$  is negative.

## Opposite limbs give twice one shift

- 1 Geometry** One limb approaches and is blueshifted; the opposite limb recedes and is redshifted.
- 2 Separation** For equal-and-opposite shifts,  $\Delta\lambda_{\text{limb}} = (\lambda_{\text{red}} - \lambda_{\text{blue}})/2$ .
- 3 Speed**  $v \approx c_0 \Delta\lambda_{\text{limb}} / \lambda_{\text{rest}}$ .
- 4 Rotation**  $T = 2\pi R/v$  if the stated geometry makes this the equatorial speed.

## Hubble law is a large-scale relationship

- 1 **Model** Hubble's law:  $v = H_0 d$ . Local peculiar motions may differ.
- 2 **Convert**  $H_0 = (70 \times 10^3 \text{ m/s}) / (3.1 \times 10^{22} \text{ m}) = 2.26 \times 10^{-18} \text{ s}^{-1}$ .
- 3 **Reciprocal**  $t_H = 1/H_0 = 1/(2.26 \times 10^{-18} \text{ s}^{-1}) = 4.43 \times 10^{17} \text{ s}$ .
- 4 **Interpret** Hubble time is an expansion timescale. Treating it as age assumes a past expansion model.

## Evidence does not settle every cosmic prediction

### Evidence

Expansion supports an earlier hotter, denser universe.

Gravitational effects unexplained by visible matter motivate dark matter.

### Inference and uncertainty

Age and fate depend on expansion history and matter content; modern models include dark energy.

One value of  $H_0$  does not by itself prove perpetual expansion or future collapse.

## Use the documents in their learning order

Reference: learn the complete knowledge, methods and assumptions.



Skill sheet: supported practice → reduced support → exam-style demands.



Authentic set: transfer to original wording; correct with reasons.



Return to the reference for a diagnosed gap; re-attempt before using reserved assessment questions.

## Check the model before the answer

### Three explanations to attempt

1. How can internal energy increase while temperature stays constant?
2. Why must background be removed before source-rate ratios or logarithms?
3. An acceleration–displacement line has slope  $-25 \text{ s}^{-2}$ . Find angular frequency and explain the negative sign.

## Check yourself

| Question                                                                       | Explanation                                                                                                                                     |
|--------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| Constant temperature but increasing internal energy?<br>Why remove background? | Molecular arrangements and potential energy can change during phase change.<br>It does not obey the test source's distance or time-decay model. |
| $a$ - $x$ gradient $-25 \text{ s}^{-2}$ ?                                      | $\omega = \sqrt{25 \text{ s}^{-2}} = 5.0 \text{ rad/s}$ . The negative sign indicates restoring acceleration.                                   |