Oscillations and mechanical waves slide deck

Physics 20

Unit D: Oscillations and mechanical waves

Simple harmonic motion

A glider returns every 0.628 s

- A 0.250 kg glider on a horizontal air track is pulled 0.060 m to the right of a paint mark and released.
- Each full out and back cycle takes 0.628 s, and the glider keeps reaching that same rightmost point.

Cycle time and the four labels

- Oscillatory motion repeats about equilibrium, and the period T is the time for one cycle.
- Frequency f equals 1 divided by T, so a shorter cycle means a larger frequency in hertz.
- In simple harmonic motion the pull back grows in step with how far you are from the middle. Amplitude is that greatest distance.

Key terms

oscillatory motion

Oscillatory motion is a repeating back and forth motion about an equilibrium position.

simple harmonic motion

Simple harmonic motion is motion due to a restoring force directly proportional to displacement from equilibrium and directed opposite that displacement.

restoring force

A restoring force pulls or pushes an object back toward equilibrium, opposite the displacement. In F = -k x, F is that force, k is the spring stiffness, and x is the displacement from equilibrium. (F = -k x)

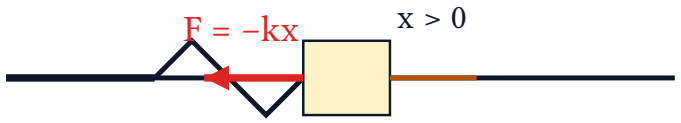
amplitude

Amplitude is the maximum displacement from equilibrium during an oscillation. (A)

The spring force points back

- The force law is F = -k x, with F in newtons, k in newtons per metre, and x the displacement from equilibrium in metres.
- The negative sign means the force points opposite the displacement when the positive direction is away from equilibrium.
- For a horizontal mass spring oscillator, T = 2 pi times the square root of m/k, and m is the mass.

Spring force law



$T = 2\pi\sqrt{(m/k)}$

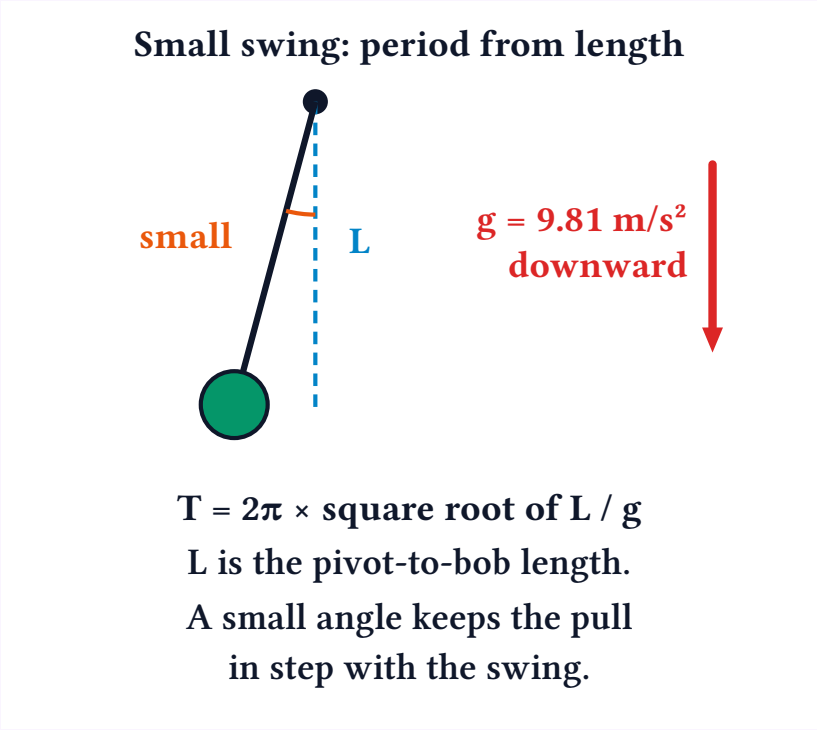
Force points toward equilibrium

Period of a 0.450 kg cart

- A cart of mass 0.450 kg is fixed to a horizontal spring with k = 18.0 N/m.
- T = 2 pi × square root of 0.450 / 18.0 = 0.993 s.
- At +0.080 m, F = -(18.0 N/m)(0.080 m) = −1.44 N.

A small swing and the pendulum clock

- For a simple pendulum at a small angle, T = 2 pi times the square root of L/g.
- The symbol L is the length from the pivot to the centre of the bob, and g is 9.81 m/s squared downward.
- Keep the swing small. Then the pull back grows in step with the distance from the middle.



A stairwell pendulum

- A stairwell pendulum has length 2.20 m and swings through a small angle.
- Find the period with g = 9.81 m/s squared.
- State the speed and the acceleration along the arc at the bottom and at the highest point.

Oscillators

- A 0.200 kg air track glider has k = 50.0 N/m and amplitude 0.040 m.
- Find the period and the restoring force at the positive amplitude.
- State the speed at the amplitude and the acceleration at equilibrium.

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Oscillator energy and resonance

Washboard ruts at 10 Hz

- A pickup west of Drumheller rolls at 8.0 m/s over gravel ruts spaced 0.80 m apart.
- The wheels meet a rut ten times each second, and the cab amplitude grows when the suspension springs share that rhythm.

Energy and stiffness

- In an ideal oscillator that keeps its energy to itself, the joules stay the same total while kinetic energy and potential energy trade places.
- The spring constant k is stiffness in newtons per metre. A pendulum period depends on length and on g, which is 9.81 m/s squared downward.
- Resonance is the big swing you get when each push matches the rhythm the object already has.

Key terms

mechanical resonance

Mechanical resonance is a large amplitude that builds when a driving frequency matches the natural frequency of an oscillator.

spring constant

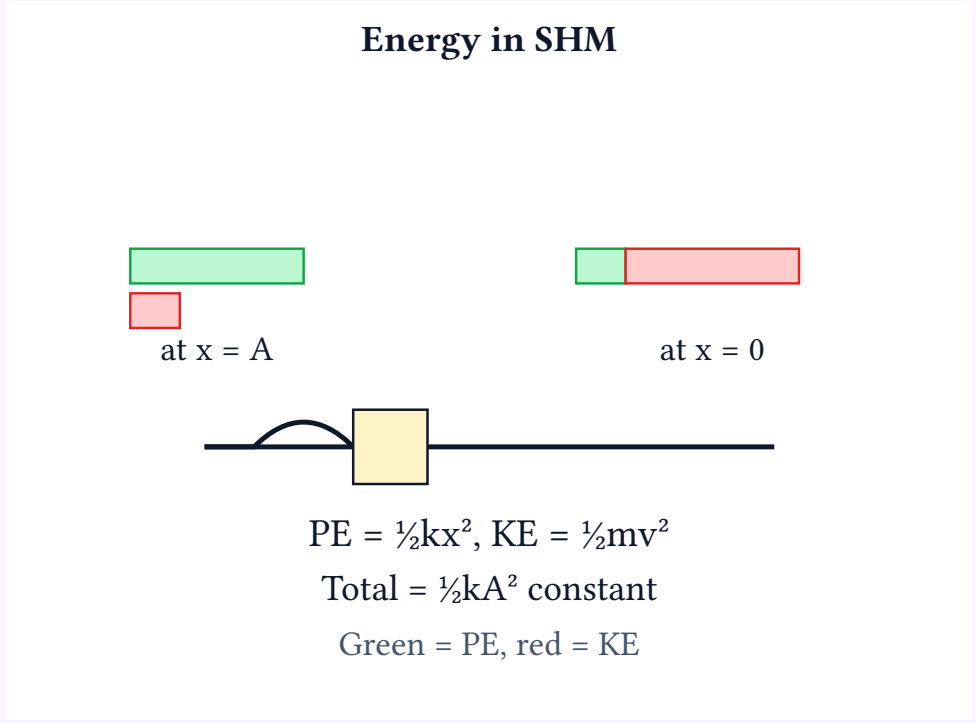
The spring constant is the stiffness of a spring, equal to the magnitude of the force divided by the stretch. (k)

pendulum

A pendulum is a bob on a string or rod that swings through a small angle about a fixed pivot. (T = 2 pi square root of L/g)

Joules trade places and the total holds

- Spring potential energy is one half k x squared, and kinetic energy is one half m v squared.
- At the amplitude the speed is zero and the total energy is one half k A squared.
- At equilibrium the potential energy is zero and the speed is greatest, with the total still equal to one half k A squared.

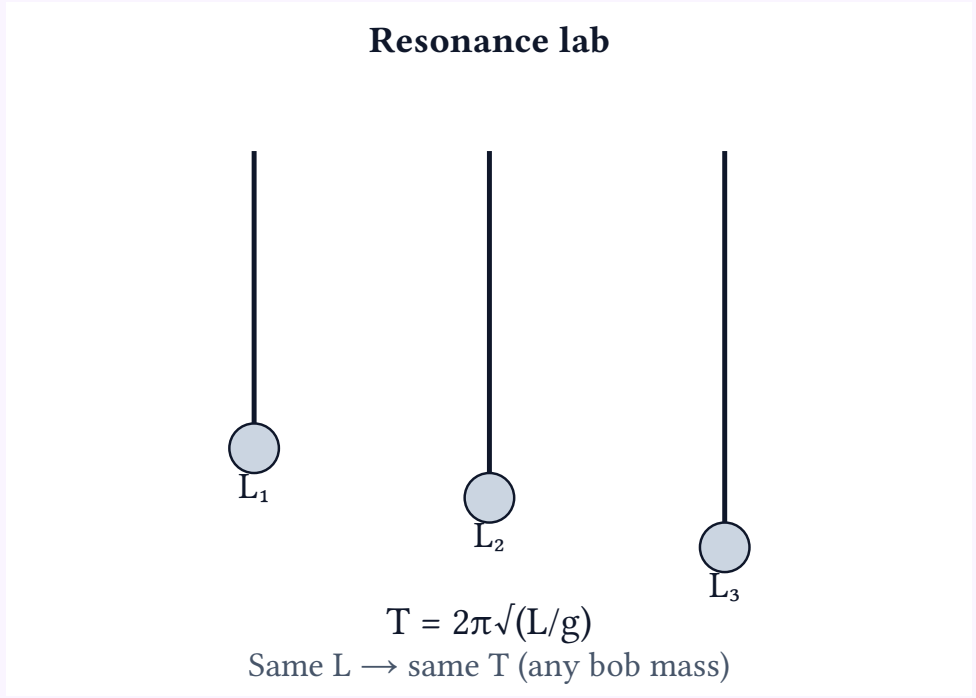


0.144 J in a 45.0 N/m spring

- A 0.180 kg block on a 45.0 N/m spring has amplitude 0.080 m.
- Total energy = one half × 45.0 × $(0.080)^2$ = 0.144 J.
- Greatest speed from one half × 0.180 × v^2 = 0.144 is 1.26 m/s.

Resonance demonstration

- Pendulum data for several lengths should follow T = 2 pi times the square root of L/g.
- Same string length and same g: a heavier bob still has the same period.
- The spring constant comes from F = k x or from the measured period, and a resonance demo stays at a modest amplitude.



Stiffness from a hanging mass

- A 0.400 kg mass stretches a vertical spring by 0.0981 m.
- Find the spring constant from the weight and the stretch.
- A tower sways naturally at 2.40 Hz. A push at 2.40 Hz builds a large sway. A push at 0.70 Hz stays small.

Stored joules and a matched driver

- A 0.180 kg block on a 45.0 N/m spring has amplitude 0.080 m.
- Find the total mechanical energy and the greatest speed.
- The natural frequency is 2.52 Hz. State what a 2.52 Hz driver does to the amplitude.

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Properties of mechanical waves

A ribbon stays while the pulse leaves

- A coloured ribbon is taped to one loop of a long coil stretched 6.0 m across the gym floor.
- A sharp push sends a compression 6.0 m in 2.40 s, and the ribbon jitters beside its tape mark.

Names for a travelling disturbance

- A mechanical wave keeps each particle oscillating near its start while energy moves forward.
- If the coil moves sideways while the pulse runs forward, the wave is transverse. If the coil pushes along the pulse, the wave is longitudinal.
- On that travelling shake you measure wavelength, wave speed, period, frequency, amplitude, the wave front, and the ray.

Key terms

mechanical wave

A mechanical wave is a disturbance in which particles of a medium oscillate in simple harmonic motion while energy travels forward.

transverse wave

A transverse wave moves particles of the medium perpendicular to the direction of propagation.

longitudinal wave

A longitudinal wave moves particles of the medium along the direction of propagation.

wavelength

Wavelength is the distance from one crest to the neighbouring crest, measured along the direction of travel. (lambda)

Key terms

wave speed

Wave speed is the speed at which the disturbance travels through the medium. (v)

wave front

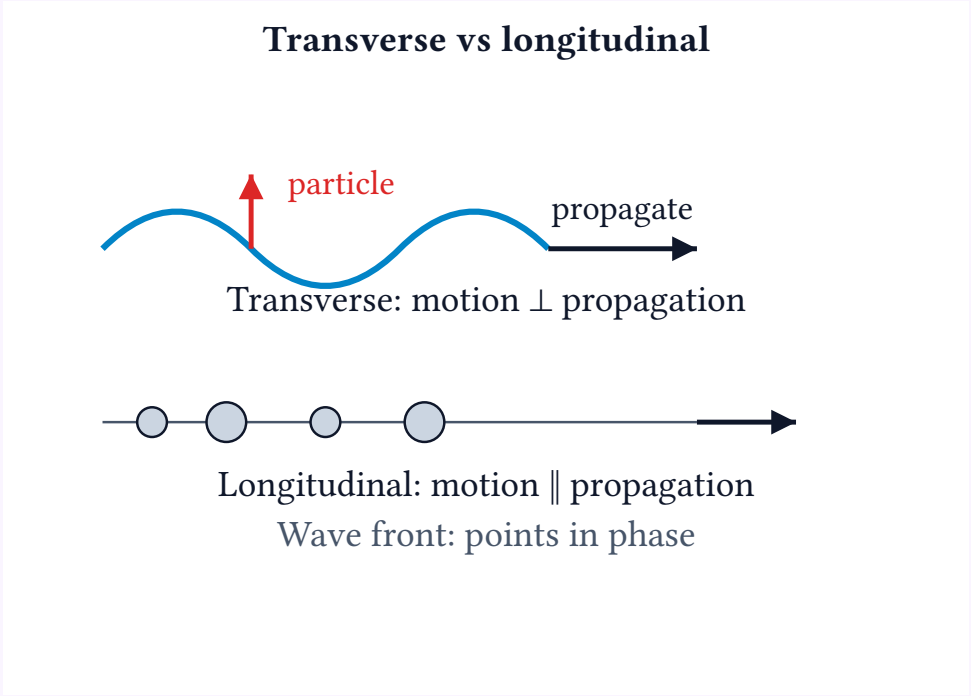
A wave front is a line or surface joining points of the medium that move together at the same stage of the cycle.

ray

A ray is an arrow drawn perpendicular to a wave front, showing the direction of energy travel.

Sideways shakes and lengthwise pushes

- In a transverse wave the particle motion is perpendicular to the direction of propagation.
- In a longitudinal wave the particle motion is along the direction of propagation.
- A wave front is a line through points that are moving together.
- A ray leaves that line at a right angle and shows where the wave is going.



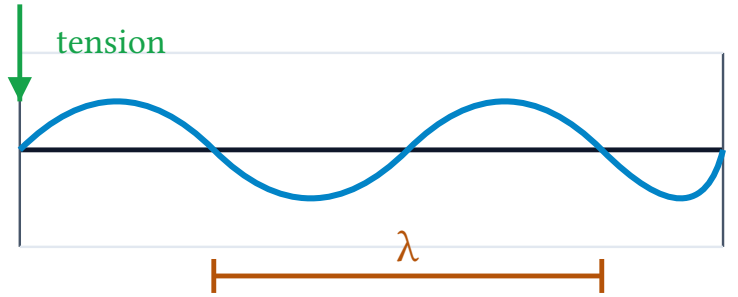
A 686 Hz whistle in warm air

- A whistle of frequency 686 Hz sounds in air at 20 degrees Celsius, where the wave speed is 343 m/s.
- Wavelength = 343 m/s / 686 Hz = 0.500 m.
- Sound in air is a longitudinal wave, so the air particles move along the ray.

The medium sets the wave speed

- Wave speed on a string depends on the tension and the linear density of that string.
- Wave speed of sound in air depends on the temperature of the air.
- With one variable changed and another held constant, v = f lambda predicts the new wavelength.

Wave speed on a medium



$$v = f\lambda$$

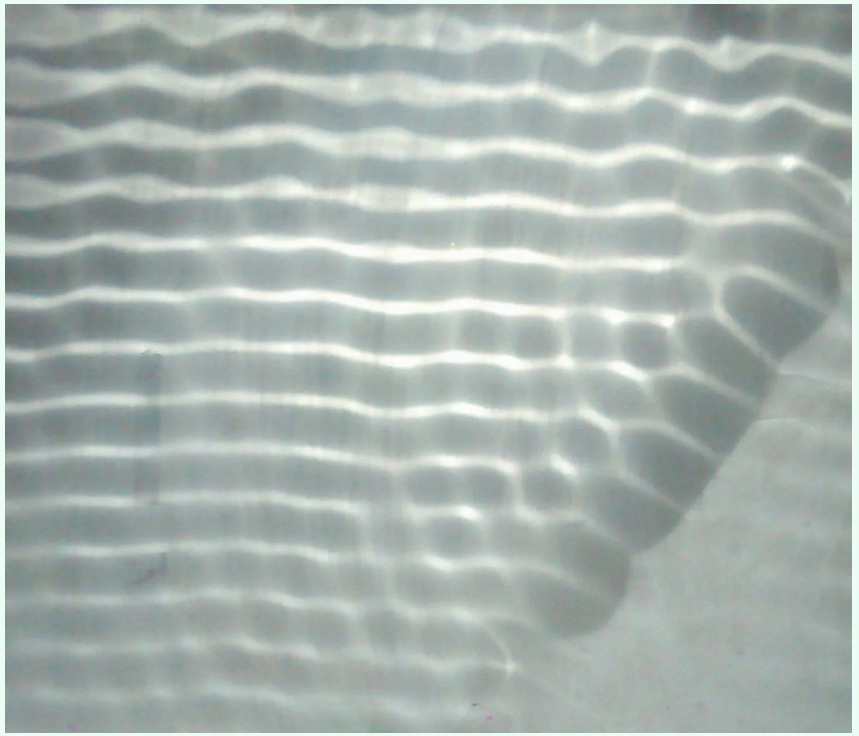
String: v set by tension & density

Sound: v set by air temperature

Hold one variable fixed to predict λ

A ripple tank held at one speed

- A ripple tank shows crests 0.125 m apart, and 4.00 crests pass a dot each second.
- Find the wave speed, then predict the wavelength if the paddle slows to 2.00 Hz in the same water.
- Verify the prediction with v = f lambda.



Harbour crests

- Harbour crests are 2.40 m apart, and a crest passes a piling every 4.00 s.
- Find the wave speed.
- Predict the new wavelength if crests pass every 2.00 s and the harbour water is unchanged.

Image credits

Psgs123xyz (talk) (Uploads)., Reflection of waves observed using a ripple tank., CC0 1.0

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Wave interference and the Doppler effect

One clamp flips the pulse

- A 4.0 cm upward pulse runs along a rope toward a clamp screwed to the lab bench.
- The pulse returns upside down, while a second rope with a free ring sends an upright pulse back.

Wave behaviour

- Reflection returns a pulse inverted from a fixed end and upright from a free end.
- Interference is what you see or hear when two waves overlap. A pipe rings loudly when the note matches the air inside.
- You stand still. A moving horn reaches your ear at a different pitch than the pitch the horn makes.

Key terms

reflection

Reflection is the return of a mechanical wave after the pulse meets an end or another boundary.

interference

Interference is the overlap of two waves at one place, giving a resultant amplitude.

acoustic resonance

Acoustic resonance is a large amplitude vibration of an air column when the driving frequency matches a resonant frequency of that column.

Doppler effect

The Doppler effect is the change in heard frequency when a sound source moves toward or away from a stationary observer. (f prime)

Crests that stack and crests that flatten

- Constructive interference happens when crests meet and the amplitudes add.
- Destructive interference happens when a crest meets a trough and the resultant amplitude drops.
- With two sources, count how many wavelengths each path is. That difference tells you whether the waves add or flatten.

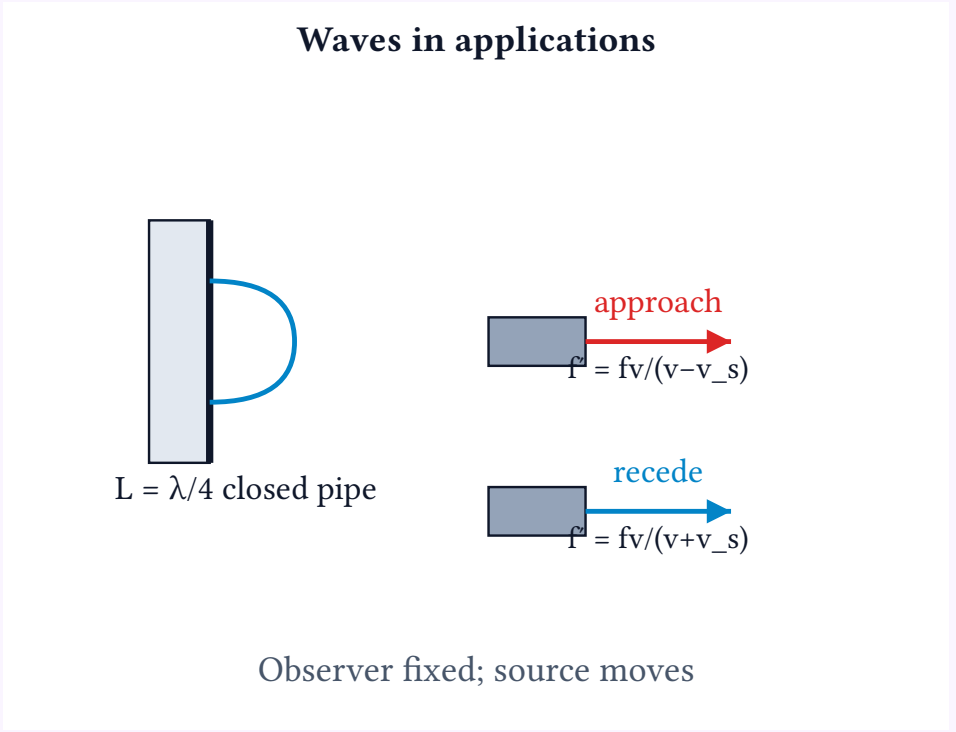


Path differences of 0.80 m and 0.20 m

- Two sources send waves of wavelength 0.40 m.
- Point A differs by 0.80 m, which is 2 wavelengths, so the waves add.
- Point B differs by 0.20 m, half a wavelength, so the waves flatten.

Applications of waves

- A closed pipe first resonates when its length is one quarter of the wavelength.
- You stand still. As the horn approaches, divide f times v by v minus the horn speed.
- As the horn leaves, divide f times v by v plus the horn speed.
- Sonography, sonar, organs, brass, noise tools, and a canoe all use wavelength and wave speed.



Resonance in a 0.180 m pipe

- Find the first resonant frequency of a closed pipe 0.180 m long when v = 343 m/s.
- Check the wave speed with 4 L f.
- Two sources of wavelength 0.40 m meet where the path difference is 0.20 m. Predict the interference.

An ambulance horn

- An ambulance siren has frequency 620 Hz and moves at 22.0 m/s in air where v = 343 m/s.
- Find the frequency heard by a stationary observer as the ambulance approaches.
- Find the frequency heard as the ambulance recedes.

Image credits

Markus Pössel, Interfering surface waves on a lake, CC BY 4.0