SKJ Education

LC HL PHYSICS

FOUNDATION PHYSICS PROGRAM: WEEK 6

WAVES & SOUND

Steven James

steven@skjeducation.com

www.skjeducation.com

SKJ Education

LC HL PHYSICS – FOUNDATION PROGRAM
Week 6: Waves & Sound

Learning Objectives

- **6.1:** To describe wave motion using key terms: displacement, amplitude, wavelength, frequency, period, and velocity.
- **6.2:** To use the wave equation ($v = f\lambda$) to perform calculations.
- **6.3:** To explain the difference between transverse and longitudinal waves, identifying sound as longitudinal.
- **6.4:** To describe the factors that affect the speed of sound.

Key Terms - Week 6

- **Wave Motion:** The transfer of energy through a medium, characterized by oscillations or vibrations.
- **Key Wave Terms:**
  - **Displacement (x):** The distance of a particle from its equilibrium position.
  - **Amplitude (A):** The maximum displacement of a particle from its equilibrium position.
  - **Wavelength (λ):** The distance between two consecutive points in phase.
  - **Frequency (f):** The number of oscillations or cycles per second, measured in hertz (Hz).
  - **Period (T):** The time taken for one complete oscillation or cycle, related to frequency by $T = \frac{1}{f}$.
  - **Velocity (v):** The speed at which a wave propagates through a medium.
- **Wave Equation:** $v = f\lambda$, relating the velocity of a wave to its frequency and wavelength.
- **Transverse Wave:** A wave in which the displacement of particles is perpendicular to the direction of propagation (e.g., light waves).
- **Longitudinal Wave:** A wave in which the displacement of particles is parallel to the direction of propagation (e.g., sound waves).
- **Speed of Sound:** The speed at which sound waves propagate through a medium, affected by factors such as temperature, pressure, and the properties of the medium.

Weekly *Challenge*: Investigate how the speed of sound varies with temperature or other factors. Design an experiment to measure the speed of sound and analyse the results. Share your findings on Google Classroom.

WEEK 6 STUDY PLAN

Day	Activities & Time Commitment	✓	Rating (1-10)
Monday	- Review Learning Objectives (5 min) - Rank your current ability (5 min) - Review Key Terms (10 min) - Complete Exercise A1 (15 min) *Focus: PREPARATION*		
Tuesday	- Complete Exercises A2 & A3 (60 min) - 1-hour online lesson (60 min) *Focus: QUESTIONING*		
Wednesday	- Reflect on content so far (what has been challenging?) (10 min) - Plan remaining study sessions (10 min) *Focus: PROCESSING*		
Thursday	- Complete Exercise B (50 min) *Focus: EXPERIMENTAL THINKING*		
Friday	- Complete Exercise C (40 min) *Focus: ERROR ANALYSIS*		
Saturday	- Complete Exam Question Assessment (D) (60 min) *Focus: EXECUTION*		
Sunday	- Correct assessment (30 min) - Complete self-reflection (15 min) - Plan next week (15 min) *Focus: REFLECTION & RECHARGING*		

Study Tips for Success

- **Active Recall:** After studying, close your notes and write down **everything you remember**. Force your brain to grow.
- **Spaced Repetition:** Review concepts **multiple times** over several days.
- **Physics in Action:** Look for **real-world examples** of the concepts you're learning.
- **Ask Questions:** Don't hesitate to ask for help when concepts are unclear. Reach out via *Google Classroom* or email; *steven@skjeducation.com*.
- **Celebrate Progress: Acknowledge your improvements**, no matter how small.

Experimental Thinking Questions:
- **Speed of Sound:** Why is it more accurate to find two resonance positions (L_1 and L_2) and calculate the wavelength as $\lambda = 2(L_2 - L_1)$ rather than just using the first position? What experimental error does this method eliminate?
- What is happening at a molecular level in the air column when resonance occurs?
- **Sonometer:** How do you ensure that the frequency you are observing is the *fundamental* frequency and not a higher harmonic?
- In the f vs T experiment, tension is applied using masses. If you double the mass on the hanger, by what factor does the frequency change?
- Why does a paper rider placed at the centre of the string jump off vigorously at resonance?

Connecting the Dots: Common Exam Pitfalls

Exam Preparation Tips

Speed of Sound in Air:
- You must state that resonance is identified when the **loudest sound** is heard.
- The most accurate way to find the wavelength is to find two successive points of resonance, L_1 and L_2. The distance between them is half a wavelength, so $\lambda = 2(L_2 - L_1)$. This eliminates any **end correction** error.
- The final calculation uses the wave equation: $c = f\lambda$. The frequency f is read from the tuning fork.
- Be able to draw the standing wave in the tube for the first and second positions of resonance.

Frequency vs. Length ($f \propto 1/L$):
- A sonometer is used. The independent variable is the length L (varied by moving a bridge), and the dependent variable is the frequency f (found using tuning forks).
- To verify the relationship, a graph of f **vs.** $1/L$ is plotted. This should yield a straight line through the origin.
- For this experiment, the **tension** of the string must be kept constant.

Frequency vs. Tension ($f \propto \sqrt{T}$):
- The independent variable is the tension T (varied by adding masses to the hanger, $T = mg$), and the dependent variable is the frequency f.
- To verify the relationship, a graph of f **vs.** $\sqrt{T}$ is plotted. This should yield a straight line through the origin.
- For this experiment, the **length** of the string must be kept constant.
- A common precaution for both sonometer experiments is to use a paper rider at the centre of the string to help identify resonance more clearly.

Video Review & Active Recall Quiz

Experiment Video Demonstrations

Watch these videos to see how resonance is found and data is recorded in these experiments.
- **Measuring the Speed of Sound:** [VIDEO LINK]
- **Sonometer - Frequency vs. Length:** [VIDEO LINK]
- **Sonometer - Frequency vs. Tension:** [VIDEO LINK]

Active Recall Exam Questions

Answer the following questions **from memory**.
1. In the experiment to measure the speed of sound, how does an observer know that the air column is resonating with the tuning fork?
2. A student finds the first position of resonance at a length of 16 cm and the second at 50 cm. What is the wavelength of the sound wave?
3. If the tuning fork used in the previous question had a frequency of 512 Hz, calculate the speed of sound in air.
4. What is meant by the "end correction" in this experiment? How can it be eliminated?
5. Draw a labelled diagram of a sonometer.
6. State the two factors that determine the fundamental frequency of a stretched string.
7. In the sonometer experiment to investigate the relationship between frequency and length, what two quantities must be kept constant?
8. What graph would you plot to verify that frequency is inversely proportional to length?
9. How is the tension varied in the experiment to investigate the effect of tension on frequency?
10. What is the function of the paper rider in the sonometer experiments?
11. Draw a diagram of the standing wave in a closed pipe at the first position of resonance. Label the node and antinode.

C. Calculation Error Analysis: Forensic Physics

> **Learning Focus:** Developing **critical analysis skills** by identifying and correcting common physics **misconceptions** and **calculation errors**.

Analysis Protocol

1. **Locate the Error:** Pinpoint the specific step or statement that is incorrect.
2. **Diagnose the Error:** Classify the error type: **Procedural Error** (miscalculation, incorrect formula application), **Conceptual Error** (misunderstanding a definition or principle), or **Omission Error** (incomplete conditions or overlooked restrictions).
3. **Explain the Misconception:** Articulate the underlying flawed reasoning or missing knowledge demonstrated by the error.
4. **Correct the Solution:** Provide the complete, accurate, and step-by-step mathematical solution.
5. **Metacognitive Reflection:** "This error (e.g., misinterpreting discriminant conditions) is subtle because the algebra might seem correct initially. What is one personal strategy I can adopt to ensure I never overlook a crucial detail like this under exam pressure (e.g., always double-checking discriminant inequalities)?"

Forensic Physics Task

Your job isn't to find the right answer, but to find the **flaw in the thinking**. Explain **_why_** each statement/calculation is wrong and **correct them**.

Error Analysis Exercises

Exercise 1: Wave Equation – Misplaced Variables
Question: A sound wave has frequency $f = 440\,\text{Hz}$ and wavelength $\lambda = 0.75\,\text{m}$. Calculate its speed.

Incorrect Calculation: $v = \dfrac{f}{\lambda} = \dfrac{440}{0.75} \approx 587\,\text{m s}^{-1}$.

Flawed Thinking

Error Analysis:

Correct Approach

Correction:

Exercise 2: Period–Frequency Conversion

Question: A wave has a period of 5.0 ms. Find its frequency.

Incorrect Calculation: $f = T \times 1000 = 5.0 \times 1000 = 5000\,\text{Hz}$.

Flawed Thinking	Correct Approach
Error Analysis:	**Correction:**

Exercise 3: Amplitude vs. Wavelength

Question: The distance between successive crests of a water wave is 1.2 m. State the amplitude.

Incorrect Statement: Amplitude = 1.2 m.

Flawed Thinking	Correct Approach
Error Analysis:	**Correction:**

Exercise 4: Wave Speed on a String

Question: A pulse travels 3.0 m along a rope in 0.20 s. Calculate the rope's wave speed.

Incorrect Calculation: $v = \dfrac{t}{d} = \dfrac{0.20}{3.0} = 0.067\,\text{m s}^{-1}$.

Flawed Thinking	Correct Approach
Error Analysis:	**Correction:**

Exercise 5: Transverse vs. Longitudinal

Question: State one key difference between transverse and longitudinal waves.

Incorrect Statement: In transverse waves, the particles move parallel to the direction of energy transfer, while in longitudinal waves they move perpendicular.

Flawed Thinking	Correct Approach
Error Analysis:	**Correction:**

Exercise 6: Speed of Sound – Temperature Dependence

Question: At 0°C the speed of sound in air is $331\,\text{m s}^{-1}$. Estimate its speed at 25°C using $v \approx 331 + 0.6T$.

Incorrect Calculation: $v = 331 - 0.6(25) = 316\,\text{m s}^{-1}$.

Flawed Thinking	Correct Approach
Error Analysis:	**Correction:**

Exercise 7: Echo Method Distance

Question: A bat emits a click and hears its echo $0.040\,\text{s}$ later. If the speed of sound is $340\,\text{m s}^{-1}$, how far away is the object reflecting the sound?

Incorrect Calculation: Distance $= vt = 340 \times 0.040 = 13.6\,\text{m}$.

Flawed Thinking	Correct Approach
Error Analysis:	**Correction:**

Exercise 8: Phase Difference Interpretation

Question: Two points on a wave are 0.20λ apart. What is the phase difference between them?

Incorrect Answer: Phase difference $= 360° \times 0.20 = 18°$.

Flawed Thinking	Correct Approach
Error Analysis:	**Correction:**

Exercise 9: Sound Intensity and Amplitude

Question: If the amplitude of a sound wave is doubled, by what factor does its intensity change?

Incorrect Statement: Intensity also doubles because it is directly proportional to amplitude.

Flawed Thinking	Correct Approach
Error Analysis:	**Correction:**

Exercise 10: Doppler Effect Sign Error

Question: A stationary observer hears a $500\,\text{Hz}$ siren from an ambulance approaching at $30\,\text{m s}^{-1}$. Take $v_{\text{sound}} = 340\,\text{m s}^{-1}$. Find the frequency heard.

Incorrect Calculation: $f' = f\left(\dfrac{v - v_s}{v}\right) = 500\left(\dfrac{340 - 30}{340}\right) = 456\,\text{Hz}$.

Flawed Thinking	Correct Approach
Error Analysis:	**Correction:**

Reflection Time

You have seen some of the common errors and misconceptions that come up in this topic. Here are some important questions to **ask yourself**:

- **What surprised you?** *Why*?

- **What did you find difficult to grasp?** *Why*?

- **Did you recognise any of *your own mistakes* during the exercise?**

- **What is the most important thing *you have learned* this week?**

Bonus Exercise

If you have finished these exercises in under 40 minutes, go and **apply your error analysis skills to *your work*** from earlier in the week!

D. Weekend Assessment – Past Exam Questions

> **Learning Focus:** Applying learning to exam questions under timed conditions. **Think deeply about these questions.**

Assessment Instructions

Answer as many questions as you can in 60 minutes - try to solve them alone first before checking your notes!

Past Exam Questions

Question 1 (2022 Deferred, Q14(b))

(i) A ray of blue light with a wavelength of 480 nm in air is incident on a rectangular glass block. Calculate the refractive index of the glass for blue light given an angle of incidence of 40° and angle of refraction of 25°.

(ii) Calculate the speed of this light in the glass.

(iii) Calculate the wavelength of this light in the glass.

Question 2 (2018, Q7)

(i) A stretched string of a violin has a length of 328 mm and emits a note of 660 Hz when it vibrates at its fundamental frequency. Calculate the speed of sound in the string.

(ii) The string has a mass of 0.126 g. Calculate the tension in the string.

Question 3 (2021, Q14(b))

(i) A moving underwater source emits a sound of frequency 800 kHz while travelling towards an underwater detector, which detects a frequency of 806 kHz. Calculate the speed of the source. (speed of sound in water = 1480 m s^{-1})

Question 4 (2014, Q10)

(i) An ambulance siren emits a sound of frequency 750 Hz. When the ambulance is travelling towards an observer, the frequency detected by the observer is 820 Hz. What is the speed of the ambulance? (speed of sound in air = 340 m s^{-1})

Question 5 (2023 Deferred, Q6)

(i) A stretched string vibrates at a fundamental frequency of 205 Hz when the tension applied is 5 N. Calculate the fundamental frequency of the string when the tension applied is 10 N.

Question 6 (2013, Q7)

(i) A sample of wire has a mass per unit length of 0.004 kg m^{-1}. A 64 cm length of the wire was fixed at both ends and plucked. The fundamental frequency of the sound produced was found to be 173 Hz. Calculate the tension in the wire.

Question 7 (2016, Q12(c))

(i) A buzzer moves at a speed of 13 m s^{-1} in a vertical circle. The buzzer emits a note of frequency 1.1 kHz. An observer stands in the plane of motion of the buzzer. Calculate the maximum and minimum frequency of the note detected by an observer. (speed of sound in air = 340 m s^{-1})

Question 8 (2021, Q5)

(i) Calculate the sound intensity 6 m from a loudspeaker of power 20 mW.

Question 9 (2022, Q5)

(i) The sound intensity is 0.18 mW m^{-2} at a distance of 3 m in any direction from a source of sound. Calculate the power of the source.

Question 10 (2011, Q8(b))

(i) An audio speaker at a concert emits sound uniformly in all directions at a rate of 100 W. Calculate the sound intensity experienced by a listener at a distance of 8 m from the speaker.

(ii) The listener moves back from the speaker to protect her hearing. At what distance from the speaker is the sound intensity level reduced by 3 dB?

Question 11 (2015, Q9)

(i) A tin whistle consists of a pipe which is open at both ends. A particular tin whistle has a fundamental frequency of 587 Hz when all of the holes on it are covered. How long is the pipe? (speed of sound in air = 340 m s^{-1})

Question 12 (2019, Q10)

(i) A certain musical instrument can be modelled as a cylindrical pipe that is closed at one end and whose length can be changed. Draw diagrams to show the first two harmonics of this instrument.

Question 13 (2016, Q5)

(i) The ear canal acts as a cylindrical pipe closed at one end. It is of average length 2.3 cm. The speed of sound in air is 340 m s^{-1}. What is the fundamental frequency of the ear canal?

Question 14 (2009, Q5)

(i) The sound intensity level at a concert increases from 85 dB to 94 dB when the concert begins. By what factor has the sound intensity increased?

Self-Assessment

After completing the assessment:
- Grade your work honestly
- Identify areas needing improvement
- Scan and submit via Google Classroom
- Reflect on your performance in your weekly reflection

Another excellent week of work completed - ***well done!*** You are another step closer to *smashing your exams*, and another week closer to your summer holdiays!

Weekly Reflection Zone

What worked well this week?

What challenges did I face?

What surprised me the most this week?

Key physics concepts I want to review:

Goals for next week: