DEVIL PHYSICS

BADDEST CLASS ON CAMPUS

IB PHYSICS

INTRO VIDEOS

Big Bang Theory of the Doppler Effect

Doppler Effect

LESSON 9.5:
The Doppler Effect

1. **Essential Idea: The Doppler Effect describes the phenomenon of wavelength/frequency shift when relative motion occurs.**
2. **Nature Of Science:**
    a. **Technology: Although originally based on physical observations of the pitch of fast moving sources of sound, the Doppler Effect has an important role in many different areas such as**

evidence for the expansion of the universe and generating images used in weather reports and in medicine.

3. **International-Mindedness: Radar usage is affected by the Doppler Effect and must be considered for applications using this technology.**
4. **Theory Of Knowledge: How important is sense perception in explaining scientific ideas such as the Doppler effect?**
5. **Understandings: The Doppler Effect for sound waves and light waves.**
6. **Applications And Skills:**
    a. **Sketching and interpreting the Doppler Effect when there is relative motion between source and observer.**
    b. **Describing situations where the Doppler Effect can be utilized.**
    c. **Solving problems involving the change in frequency or wavelength observed due to the Doppler Effect to determine the velocity of the source/observer.**
7. **Guidance:**
    a. **For electromagnetic waves, the approximate equation should be used for all calculations**

b. **Situations to be discussed should include the use of Doppler effect in radars and in medical physics, and its significance for the red-shift in the light spectra of receding galaxies**

8. **Data Booklet Reference:**
    a. **Moving source:** $f' = f\left(\frac{v}{v \pm u_s}\right)$
    b. **Moving observer:** $f' = f\left(\frac{v \pm u_s}{v}\right)$
    c. $\frac{\Delta f}{f} = \frac{\Delta \lambda}{\lambda} \approx \frac{v}{c}$
9. **Utilization: Astronomy relies on the analysis of the Doppler effect when dealing with fast moving objects (see *Physics* option *D*)**
10. **Aims:**
    a. **Aim 2: the Doppler effect needs to be considered in various applications of technology that utilize wave theory**
    b. **Aim 6: spectral data and images of receding galaxies are available from professional astronomical observatories for analysis**
    c. **Aim 7: computer simulations of the Doppler effect allow students to visualize complex and mostly unobservable situations**

3. **Definition: The Doppler Effect is the change in the frequency of a wave received by an observer compared with the frequency with which it was emitted. The effect takes place whenever there is motion between the emitter and receiver.**

   a) **Consider first a stationary source:**

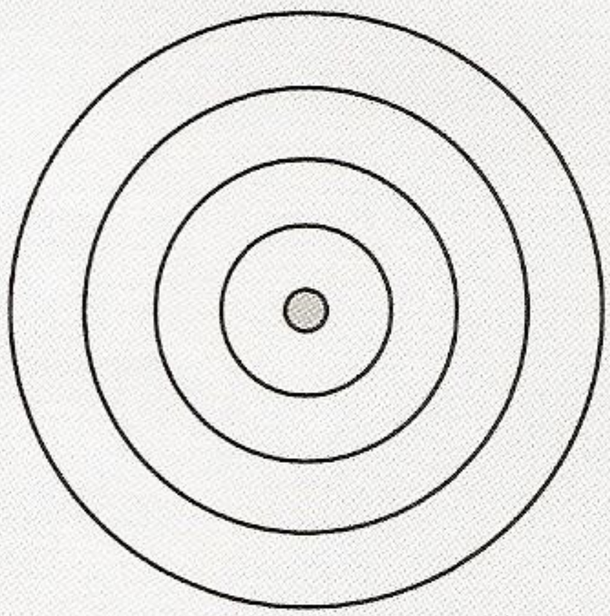

Figure 5.1 The wavefronts emitted by a stationary source are concentric. The common centre is the position of the source.

a) Now consider a moving source:

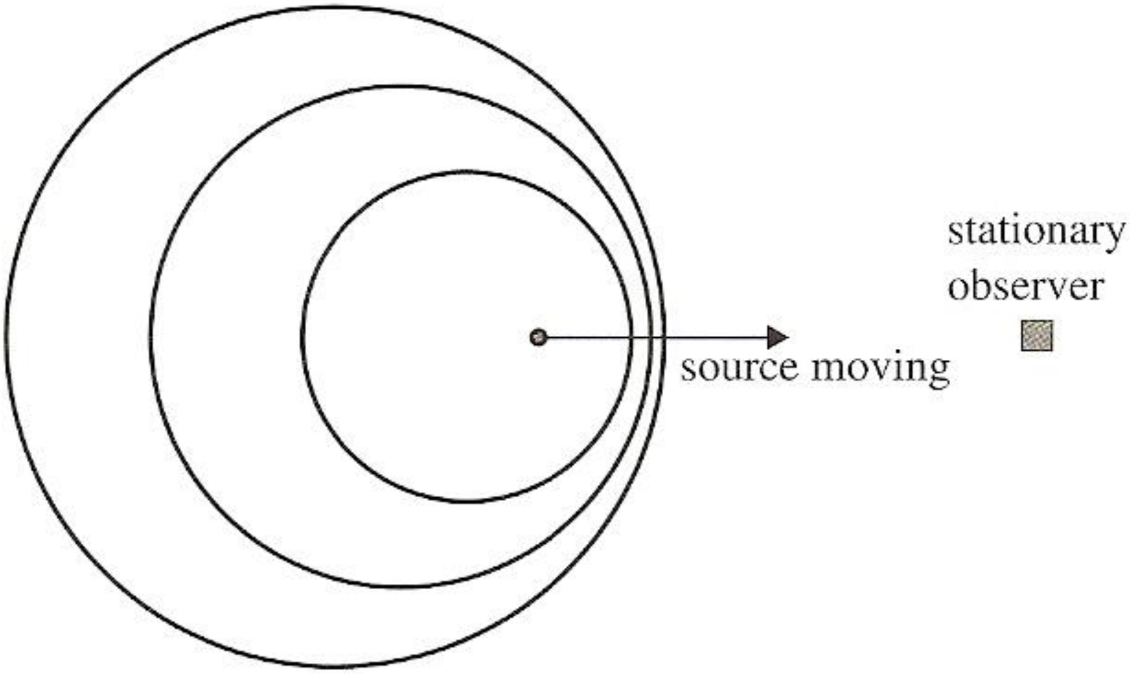

Figure 5.2 A source is approaching the stationary observer with speed v_s.

b) The time between wavefronts is the period, T

c) If the source is travelling at a speed v_s, in the time between emitting two successive wavefronts (T), the source will have moved a distance of $d_s = v_s T$

d) To the observer, the received wavelength will be $\lambda_o = \lambda_s - d_s$

4. **Derivation**

e) **for <u>source</u> moving <u>toward</u> <u>observer</u>:**

$$\lambda_o = \lambda_s - d_s = \lambda - v_s T$$

$$T = \frac{1}{f}$$

$$f = \frac{c}{\lambda}$$

$$T = \frac{\lambda}{c}$$

$$\lambda_o = \lambda_s - v_s \frac{\lambda_s}{c}$$

$$\lambda_o = \lambda_s \left(1 - \frac{v_s}{c}\right)$$

i) **Since λ_o is the wavelength perceived by the observer and since $f = \frac{c}{\lambda}$, then the frequency perceived by the observer is**

$$f_o = \frac{c}{\lambda_o}$$

$$f_o = \frac{c}{\lambda_s \left(1 - \frac{v_s}{c}\right)}$$

Since $f_s = \frac{c}{\lambda_s}$, we can factor this out,

$$f_o = f_s \frac{1}{\left(1 - \frac{v_s}{c}\right)}$$

$$f_o = \frac{f_s}{\left(1 - \frac{v_s}{c}\right)}$$

a) **for <u>source</u> moving <u>away</u> from the <u>observer</u>:**

ii) **The difference will be that the observed wavelength will be greater than the wavelength emitted by the source by an amount equal to the distance travelled by the source in the time between emissions, which is the period, T**

$$\lambda_o = \lambda_s + d_s = \lambda + v_s T$$

i) **Using the same derivation as above, the result is**

$$f_o = \frac{f_s}{\left(1 + \frac{v_s}{c}\right)}$$

a) **For <u>observer</u> moving <u>toward</u> <u>source</u>:**

i) **While you would think the same formulas would work, this situation is different.**

ii) **In this situation, the wavelength perceived by the observer is <u>the same</u> as that emitted by the source ($\lambda_o = \lambda_s$), only the velocity of the waves is changed with respect to the observer**

iii) In other words, since the source is stationary, the waves it emits are all still the same distance apart. But since the observer is moving toward the source, he perceives the waves as coming at him more quickly by an amount equal to $v' = c + v_o$

iv) This will, in turn, affect the frequency:

$$f_o = \frac{v'}{\lambda_s} = \frac{c + v_o}{\lambda_s}$$

Since $f_s = \frac{c}{\lambda_s}$ and $\lambda_s = \frac{c}{f_s}$,

$$f_o = \frac{c + v_o}{\frac{c}{f_s}}$$

$$f_o = f_s \frac{c + v_o}{c}$$

$$f_o = f_s \frac{c\left(1 + \frac{v_o}{c}\right)}{c}$$

$$f_o = f_s \left(1 + \frac{v_o}{c}\right)$$

a) For observer moving away from source:

i) Using the same line of thinking, in this situation the perceived wavelength is still the same as that emitted by the source, but because the observer is moving away from the source, the waves hit the observer at a lower velocity, $v' = c - v_o$

ii) Using the same derivation, the result is

$$f_o = f_s\left(1 - \frac{v_o}{c}\right)$$

5. **Summary of the four cases:**

a) Source moving toward observer:

$$f_o = \frac{f_s}{\left(1 - \frac{v_s}{c}\right)}$$

a) Source moving away from observer:

$$f_o = \frac{f_s}{\left(1 + \frac{v_s}{c}\right)}$$

b) Observer moving toward source:

$$f_o = f_s\left(1 + \frac{v_o}{c}\right)$$

c) Observer moving away from source:

$$f_o = f_s\left(1 - \frac{v_o}{c}\right)$$

6. **What formulas are you provided with in your Data Guide?**

Tsokos	**Data Guide**
Moving Source: $f_o = \frac{f_s}{\left(1 - \frac{v_s}{c}\right)}$ $f_o = \frac{f_s}{\left(1 + \frac{v_s}{c}\right)}$	**Moving Source:** $f' = f\frac{v}{(v \pm u_s)}$
Moving Observer: $f_o = f_s\left(1 + \frac{v_o}{c}\right)$ $f_o = f_s\left(1 - \frac{v_o}{c}\right)$	**Moving Observer:** $f' = f\frac{v \pm u_o}{(v)}$

7. **Note that in the case of a moving source, the perceived (and actual) wavelength changes, but with a moving observer, the wavelength is the same. That is why we define the Doppler Effect in terms of observed frequency.**

SUMMARY VIDEO

The Doppler Effect

LESSON 9.5: HOMEWORK

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