Lab 4:
The Doppler Effect for Sound,
With Vernier Video Simulation

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*** NOTE: Every Triple-Starred Direction (***) is a direction in response to which you must write something down. Every lab write-up requires at least your written responses to all ***'d directions. (Some write-ups may require more. Always check the web to see if there is a particular set of supplementary lab write-up instructions due for a given lab period.)

A. Goals:

1. To grow comfortable with the Vernier/LoggerPro approach to laboratory video analysis.
2. To understand qualitatively why and how wave frequency depends on reference frame—according to the Doppler Effect.
3. To predict, compute and verify the quantitative details for sound frequencies that differ according to the Doppler Effect.

B. Necessary Equipment

1. Laptop computer
2. Software: LoggerPro software
3. Software: "Vernier Physics with Video Analysis", "23. Doppler Sound".

C. Vernier Background and Credit

Vernier, a signature company in physics education lab equipment, has created movies of a honking car moving fairly rapidly on a straight level road past a stationary microphone. They have recorded the sound waves emanating from the car's horn separately using a sound sensor attached to the Logger *Pro* interface, operated by the roadside observer. They have also written significant portions of the text to follow. You will be working with these files in this exercise.

Your goal in this assignment is predict and verify the ratio (fF / fB) of the received car horn frequencies before and after the car passes the microphone. To complete this assignment you will need to use your knowledge of:

a) How wave speed relates to wavelength and frequency ***and***
b) Your knowledge of Galileo's Principle of Relativity (hint: Form #4)

or

c) Any specific knowledge/relations/equations you have gleaned from recent chapters in your text

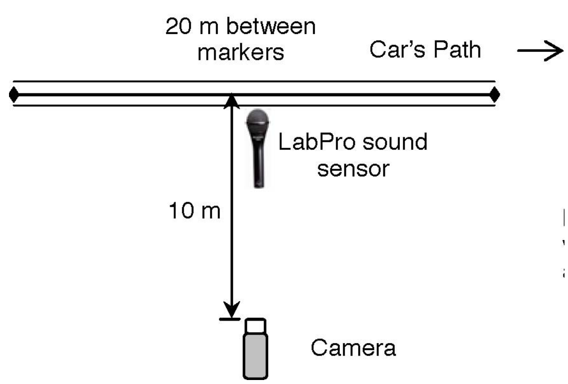
in order to

(1) derive this ratio as a function of the speed of sound waves relative to air (v_{wa}) and the speed of the car horn relative to air(v_{sa}), and then

(2) use the Logger *Pro* video analysis tools to determine the value of v_{sa}–the car's velocity relative to air.

D. FUNDAMENTALS: ANALYSIS & PREDICTION

(a) Open the movie entitled <CarHornDoppler.mov> and play it. This video clip was recorded by a digital video camera that was placed perpendicular to the road and 10.0 meters away from the center of the car just as it passes the sound sensor in the center of the frame as shown in Figure 2. The sound dubbed into the *Car Horn Doppler* movie was recorded at the roadside by this sound sensor.



(b) ***** In a complete sentence or two of English, describe any changes you observe in the sound of the car's horn as is passes the sound sensor. Specifically address both the sound's volume and the sound's pitch.** Put another way, what happens to the sound of the car's horn as the car moves from an initial position to the left of the camera to a final position to the right of the camera? Replay the movie and listen several times, does the frequency of sound change? Is the loudness changing? Describe what you hear.

Verification of the Doppler Equations: In the section you are going to use the Logger *Pro* software along with the movie of the car's motion and the sound sensor data to verify the Doppler Equations.

(c) *** FORMAL ANALYSIS (deriving a mathematical relation):

Use (C) (a), (b) and/or (c) (descried above) in order to derive an equation for the ratio f_F/f_B as a function of the speed of sound waves in air (v_{wa}) and the speed of the moving car horn (v_{sa}). Show all work.

E. DATA COLLECTION

(a) Open the Logger *Pro* file entitled <CarSpeed.cmbl>, which has a shortened version of the movie inserted in it.

*** i. Use the video analysis tools to find the speed of the car with its blowing horn "sound source," (v_{sa}).
*** ii. Explain what you did to find (v_{sa}).
*** iii. Record your value for (v_{sa}) to three significant figures.
*** iv. Provide a full uncertainty analysis. This must include:
- a fractional uncertainty for the distance measurement,
- a fractional uncertainty for the time measurement,
- a fractional uncertainty for the combined uncertainties,
- a final absolute uncertainty – measured in meters/sec – for the v_{sa} value.

Hint: Don't forget to scale the movie and figure out how to find the car's velocity using *x* vs. *t* data.

(b) **Calculate the speed of sound on the day the movie was made:** It turns out that the speed of sound in air (v_{wa}) depends on the air temperature (T_c), according to: $v \approx 331\ m/s\sqrt{1+\frac{T[°C]}{273°C}}$.

When the movie was made, the air temperature (T_c) was recorded as 27.2°C.

*** Calculate the speed of sound in air (v_{wa}) on that day. Show all work.

(c) *** Find the expected value of the ratio f_F/f_B in terms of your calculated value of the speed of sound in air (v_{wa}) and your measured value of the speed of the sound source (v_{sa}). **That is**: Use the equation you derived in Part (D)(c). Show your calculations and round your answer to three significant figures.

G. COMPARING PREDICTION TO DATA

(d) **Compare your calculated Ratio with Logger *Pro* frequency measurements**: This comparison serves as a direct test of the validity of the Doppler Equations. We have recorded the sound pressure using a LabPro Sound Sensor placed at the side of the road for about one second before the car passes the sound sensor and for about one second after it passes the sensor. In each case the Logger *Pro* a *Fast Fourier Transform* analysis (FFT) of the sound pressure waves can be used to find the predominant frequency just before (f_F) and just after (f_B) the car passes the roadside sound sensor.

Start by opening the Logger *Pro* file entitled <FrequencyShift.cmbl>. Look for the largest peak on the FFT graph describing the frequencies between 0 s and 1 s to find the predominant frequency just **before** (f_F) the car passes the sensor. Change the scale on the horizontal axis so that you see this region in more detail. You can accomplish this by selecting the ***Additonal Graph Options → FFT Graph Options*** from the ***Options*** menu or by double clicking on the FFT graph to reset the frequencies displayed so that you focus only on the highest amplitude frequencies. Next, use the ***Examine*** tool to find the predominant frequency just **before** (f_F) the car passes the sensor. Repeat the procedure between 2 s and 3 s to find the predominant frequency just **after** (f_B) the car passes the sensor.

*** Summarize your results in the appropriate spaces below and calculate the ratio f_F/f_B.

FFT Max 0s to 1s: f_F = _______________ Hz

FFT Max 2s to 3s: f_B = _______________ Hz f_F/f_B = ____________

F. REFLECTIONS for FINDINGS

(a) *** How did the ratio f_F/f_B that was determined from the Doppler Equations compare to the ratio determined from direct measurements? Find the percent difference between the two results. Compare this to the uncertainty analysis you provided.

(b) *** Suppose you are assisting a policeman, who is sitting in stationary cruiser and is pointing his radar "gun" at the approaching car. His detector shows the car's speed. Describe how you could use your sound data for the car's resting frequency f_0 and measured frequency f_F while moving toward the policeman to calculate the speed of an approaching car (v_s) in order to check the reliability of the radar gun.