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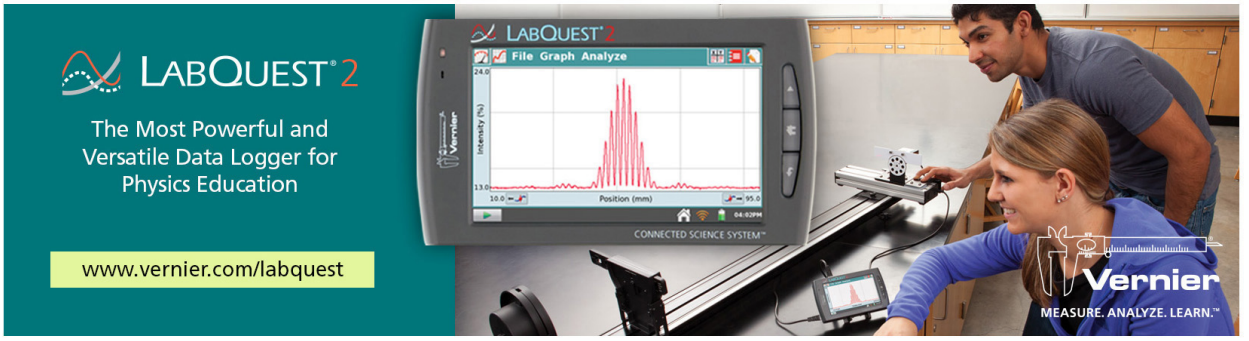

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Fermi Problems on Gasoline Consumption

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The method of obtaining a quick approximation to a seemingly difficult mathematical process by using a series of "educated guesses" and rounded calculations is attributed to nuclear research physicist Enrico Fermi (1901–1954). The most famous such problems were popularized by Fermi himself: the dropping of paper confetti during the first atomic bomb detonation to calculate the yield in equivalent tons of TNT, the number of piano tuners in Chicago, and the amount of rubber that wears off in each rotation of an automobile tire.[1]

There are many opportunities to present contemporary Fermi problem calculations to our students; they often act as effective thought motivators. For example, you might start out asking the class how many gallons of gasoline are consumed by all motor vehicles in the United States in one year. The solution might go like this: Assume that there are 2×10^8 vehicles that go an average of 10^4 miles and get an average of 20 miles per gallon (mpg). That means that each vehicle uses 10^4 miles/20 mpg = 5×10^2 gallons of gas each year; 2×10^8 vehicles times 5×10^2 gallons per vehicle equals 10^{11} (100 billion) gallons.

To expand on this concept and introduce the social factors that influence gasoline consumption, let's make the assumption that since its introduction, the Sport Utility Vehicle (SUV) has become so popular that it now makes up 5% of all passenger vehicles. If each SUV replaced a mid-sized sedan, how much will this fleet of SUV's add to the U.S. annual consumption of gasoline? Here is a possible solution: Assume 1.6×10^8 cars in the U.S. fleet; so $1.6 \times 10^8 \times 0.05 \times 10^{-2} = 8 \times 10^6$ SUV's that replace mid-sized cars. If each new car averages 1.5×10^4 miles per year and an SUV averages 15 mpg, whereas a mid-size sedan averages 20 mpg, an SUV would consume 1.5×10^4 miles/15 mpg = 1×10^3 gallons per year. The mid-size car would have used 1.5×10^4 miles/20 mpg = 7.5×10^2 gallons, so the extra fuel consumption is about 1000 – 750 = 250 gallons. The extra fuel consumed because of this trend would be 8×10^6 vehicles times 2.5×10^2 gallons, which equals 2×10^9 gallons or a 2% overall increase in gasoline consumption in the United States.

Now let's do a calculation that uses more physics concepts. Let's assume that the United States passes a law that requires all motor vehicles to drive with their headlights on at all times (similar to the law currently in effect in Canada). How much extra gasoline would this law cause to be consumed? If you say none, go back to the beginning of your first physics course and start over again! Let's try the calculation assuming that the headlights draw 100 watts and that the energy content of a gallon of gasoline is 1.2×10^8 joules/gallon. If the average vehicle goes 10,000 miles per year and averages 40 miles per hour (mph), the car would be operating 10,000 miles per year/40 mph = 250 hours each year. If currently 60% of the car's driving time occurs during daylight in dry weather without lights, then it would be driven 250 hours × 0.60 = 150 hours per year additionally with its

Fermi Questions

1) If the area of the continental United States (the 48 contiguous states) were divided equally among all the high-school physics teachers in the country, how many square meters would each one get?

2) Given normal lifetime expectations, how many more seconds does each of you have yet to live?

3) A tuning fork sounds concert A so that the orchestra can tune. The tuning fork can still be heard 20 seconds after it is struck. How many vibrations have occurred during the 20 seconds?

4) Suppose five of you could stand on each others' shoulders to form a human tower. Now imagine someone making a pile of typing paper, placing sheet on sheet until the pile is as tall as your human tower. How many pieces of typing paper would it take?

5) If five of you sumbmerge yourselves at the same time in a cylinder of water 3 meters deep and 2 meters in diameter, how many centimeters would the water rise?

Editor's comment: These questions were used as one of the contests for a high-school Physics Olympics held at State University of New York at Stony Brook.

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lights on under the proposed new law. The 150 hours per year times 100 watts × 3600 s/h = 5.4×10^7 joules of electricity per year. If the efficiency of the car engine and alternator is 10%, then we would need ten times that amount of fuel or 5.4×10^8 joules of gasoline to produce this electricity. This comes to 5.4×10^8 joules/1.2×10^8 joules/gallon = 4.5 gallons per vehicle. Since there are about 2×10^8 vehicles in the United States, that means 4.5 gallons per vehicle times 2×10^8 vehicles $\approx 10^9$ extra gallons of gas consumed if this law is passed. The question our lawmakers have to consider is: Does increase in safety justify the economic and environmental cost?

Your students will soon realize that they have the ability to make reasonable calculations with minimal effort and perhaps in the process will see that physics can be related to social and economic issues. Now, I wonder how much extra gasoline is consumed by the air drag of all those hood ornaments on Mercedes automobiles....

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Reference

1. Hans Christian von Baeyer, *The Fermi Solution* (Random House, New York, 1993), pp. 1–8.

Trick of the Trade

Quick Measurement of Wavelength of Laser Light

A freshly derived equation should be put to the test as soon as possible. I find it useful to do a lecture demonstration to measure the wavelength (λ) of laser light right after the far-field approximation equation for double-slit interference ($n\lambda = d \sin\theta$) has been developed.

The problem with this demonstration lies in the fact that the value for the slit spacing (d) must either be determined with a traveling microscope or read from its specifications, both unsatisfactory under lecture conditions. Taking a clue from the Physical Science Study Committee (PSSC) physics course of 40 years ago, I do this experiment with a layer of spray paint covering a glass plate. Two parallel slits are cut in the paint with a razor knife, keeping the slits between 0.5 and 1.0 mm apart. The spacing can be measured by cutting two other parallel slits through the paint a known distance apart. The plate is placed on an overhead projector, which enlarges the distance between the slits. In a recent demonstration, the image of two slits 2 cm apart was 12 cm apart on the screen. The image of the interference slits had a spacing of 0.7 cm, giving $d = (2/12)(0.7) = 0.12$ cm.

The class observed the interference pattern on a wall 1.2×10^3 cm distant; a student made a record of the maxima on a sheet of paper. The spaces between 11 maxima added up to 6.5 cm, giving a spacing of 0.65 cm. The angle between adjacent maxima was thus $\theta = 0.65/1.2 \times 10^3 = 5.4 \times 10^{-4}$ radians. For an angle this small, the small-angle approximation applies, and $\lambda = d\,\theta = (0.12)(5.4 \times 10^{-4})$ or 6.5×10^{-5}cm. The standard value for the wavelength of red HeNe light is 6.328×10^{-5}cm.

The largest uncertainty is the measurement of the slit spacing, which is controlled by the demonstrator's ability to measure the distance between the enlarged images of the two slits. This is of the order of 10%.

Students who see or do this experiment will probably never have trouble with the idea that the slit spacing must be equal to or less than the wavelength, since the slit spacing is clearly visible to the naked eye.

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