

1. Careful measurements show that burning one gallon of gasoline or fuel oil produces about 121 **million** joules of heat energy. (See *Scientific American*, December 1994, page 115.) An engine can utilize only some of that energy; the rest is wasted.
 - * a. Estimate today's price of heat energy from those fuels in dollars per kW-hr. (Show how.)
 - * b. Compare 1a with the price of electrical energy. (See 13b on RS V.)
 - * c. Suggest some possible reasons for the difference between those energy prices.
2. On page 66 we found that the force needed to propel a typical small car at highway speed is roughly 100 pounds. Such a car consumes about one gallon of gasoline for every ___ miles of normal driving.
 - a. Using #14 on RS VI, we find that the engine extracts roughly _____ foot-pounds, or _____ J of work from one gallon. The rest of the gasoline energy is converted into _____ by the engine.
 - b. The ratio of useful work done by the engine to the energy consumed is called the engine's "efficiency". Show how the efficiency of this typical car is calculated as a percentage: _____
3. Our typical small car weighs about 2200 pounds. RS II says 56 mph = ___ m/s.
 - a. Use 8 & 9 on RS III estimate the car's mass: (_____) (_____) = _____
 - * b. Use the "work and energy theorem" (#8 on RS VI) to determine the amount of work needed to accelerate the car from 0 to 56 mph if there is no rolling friction and no drag to retard its motion.
 - * c. Use 2a to estimate the amount of gasoline needed to do that work.
 - d. Choose a reasonable number of seconds required for such a car to accelerate from 0 to 56 mph: _____
 - * e. Use that number with 3b to estimate the engine's power. Then convert it to kW and to horsepower.
 - * f. How does the driver of an automobile control the power of its engine?
4. Let's continue pretending that the backward forces can be ignored, as we did in #___ above.
 - a. Mr. Newton tells us that the propelling force can be calculated by _____ing the car's _____ by its _____. In equation language, $\mathbf{F} = \underline{\hspace{2cm}}$.
 - b. Using "P" for power, "M" for mass, "a" for acceleration, and "S" for speed, and using #12 on RS V, we find that $\mathbf{P} = \underline{\hspace{2cm}}$.
 - c. By rearranging 4b we can predict the car's maximum acceleration at any given speed: $\mathbf{a} = \underline{\hspace{2cm}}$
 - d. Under these conditions 4c tells us that the maximum acceleration possible at 30 mph is just _____ of the maximum acceleration possible at 15 mph. (Insert a fraction.)
 - e. Now we understand why a car's speed-time graph is curved when the pedal is floored. It's because the engine's _____ does not change while the car accelerates. *Illustrate by sketching the graph.*
5. The car in #2 experienced a rolling friction force which does not depend strongly upon speed, and a drag force which *does* depend upon speed.
 - a. According to #11 on RS V, the drag force is proportional to speed to the ___ power.
 - b. At 60 mph the drag force was about 50 lb. Using 5a with 17d on RS II, we find that the drag force at 50 mph must be roughly _____. (Show how.)
 - c. At 50 mph the rolling friction force on the car is about _____ pounds _____ward. The sum of the two backward forces (drag and rolling friction) is now roughly _____ + _____ = _____.
 - d. Mr. Newton says the total force on the car must be _____ when the car is not accelerating.
 - e. To keep the car moving forward at 50 mph we need a propelling force of about _____ instead of the 100 lb. mentioned in #2. (Use 5a and 5d.)
 - f. The energy needed to drive the car some distance at 50 mph is roughly _____ times the energy needed at 60 mph. *Please express that ratio in decimal form.*
 - g. Reducing the speed from 60 to 50 mph will _____crease your fuel consumption by roughly _____%
 - h. The percentage improvement in gas mileage is about _____ times the percentage reduction in speed.
6. Imagine driving the same car at much greater speed, as you would in a race. In this case the backward _____ force is much greater than the other backward force mentioned in 5. To make our estimation easier let's pretend that the smaller of the two backward forces can be ignored.
 - a. Using "K" as a proportionality constant, write an equation for predicting the force needed to propel the car at any great speed. (Use 5a.) $\mathbf{F} = \underline{\hspace{2cm}}$ Estimate the "K" value for the car in #5. _____
 - b. Use 6a with #12 on RS VI to show how we can calculate the engine power required to drive the car at any chosen speed under these conditions. (Express it in terms of "K" and the speed.) $\mathbf{P} = \underline{\hspace{2cm}}$
 - c. Given the K value and the engine power, how can the car's top speed be estimated?
 - * d. Use the data in 3e and 5b to predict the car's top speed in mph. Show your method clearly.

1. Let "R" represent the length of a windmill's blades. When the wind is steady, the air that is going to pass between the blades during a future time interval lies in a cylindrical region along the axis of the windmill.
 - a. Write a formula for the length of the cylinder in terms of wind speed and time interval: _____
 - b. Write a formula for the volume of that cylinder: _____
 - c. Show how the kinetic energy of the air in that cylinder can be calculated: _____
 - d. Assuming 100% efficiency (which is absurd) show how a windmill's maximum power can be estimated from the air density, wind speed, and blade length.
Remember to define your symbols and to simplify your result.
 - e. How big would an ideal windmill have to be in order to power a reading lamp in a light breeze?
 - f. How about a toaster? _____ *Show how those estimates are made, using SI units.*

2. Imagine a flat plate or sail with area "A" held up so the wind blows perpendicularly against it. If the plate is not allowed to move, the wind will exert maximum force against it but will do no work on it. If the plate is allowed to move with the same velocity as the wind, then the force exerted on it by the wind will be zero; once again there will be no work done on it by the wind. It seems that work can be done only if the plate is allowed to move at a speed somewhere between zero and the wind speed. It seems likely that a similar compromise must be made for windmills.

Let "W" represent the wind velocity, i.e. the velocity of the air relative to the ground.
 Let "v" represent the velocity of the plate relative to the ground,
 Let " ρ " represent the density of the air.
 Remember to check units as you answer the questions below:

 - a. Write a formula for the mass of the air that will encounter the windmill during a time interval. (Notice that it depends on a **relative** velocity.) _____
 - b. Assuming that the encounter reduces the air velocity to "v", express the change in momentum experienced by that batch of air. _____
 - c. Express the impulse delivered to the windmill by that batch of air. _____
 - d. Express the force exerted on the windmill by the wind in terms of v, W, ρ , and A.
(Compare with the formula derived on page 56.) Remember to check units! _____
 - e. How can you calculate the work done by that force during the time interval? _____
 - f. Express the windmill's power in terms of v, W, ρ , and A. _____
 - g. Sketch a graph of power vs. v. At roughly what "v" value do we get maximum power?
(Express the optimum "v" in terms of W, and explain how you found your answer.) _____
 - h. Express the maximum power in terms of ρ , A, and W. _____
 - i. Compare this with the theoretical power formula derived in #1. According to this simplified model, how efficient can a windmill be? (Explain your reasoning.) _____

3. Actually, #2 is too pessimistic. Back in 1920, A. Betz showed that the assumption that we made in part b is incorrect. We assumed there that the collisions between the air molecules and the windmill blades were inelastic, but that is not necessarily true. A well-designed windmill behaves more as if the collisions were *elastic*. (See **A Windmill's Theoretical Maximum Power** by David R. Inglis, American Journal Of Physics 47[5], May 1979.) Use that fact to improve your efficiency estimate. Explain your logic clearly.