Imagine a police officer sending radar waves toward a car which is moving toward the officer. Waves striking the car will be reflected. The returning waves are detected by a radar wave detector. You are going to figure out how the returning waves differ from the original waves, and how the speed of the car can be determined from that difference. You will need symbols to represent each of the following quantities:

Speed of radar waves relative to ground = ____
Speed of car relative to ground = ____
Wavelength before reflection = ___
Wavelength after reflection = ___

1. Suppose the car is not moving. Using the four symbols defined above, write a formula for the time interval between the arrival of one wave at the front of the car and the arrival of the next at the front of the same car: **T_o =** ____

2. You can use similar reasoning to figure out the time interval for a *moving* car, but you must use the speed of the wave relative to the ______.
   a. If the car is moving **toward** the wave source, then the speed just mentioned can be predicted with formula 8b on RSII. Using the symbols defined on this page, we get:

      new wave speed = ___ + ____

   b. Using the same four symbols, write a formula for the time which must pass between the arrival of one wave and the next in this case: **T' =** _____

3. How can you use T' along with the other quantities listed above to figure out how far the *car* moves during that time interval? **d =** ____

4. Now think about the distance which the reflected wave moves during that same time interval:
   a. What symbol already represents that distance? ____
   b. Write an equation relating that distance to T' and one of the listed symbols.

5. The line below represents a simple map.
   Point A is the location of the car's front when the first wave hits it.
   B is the location of the front of the car when the second wave hits it.
   C is the location of the first wave (reflected) at the time when the second wave hits the car.
   D is the location of the second wave (not reflected) at the time when the first wave strikes the car:

   A B C D

   a. Which of the symbols on this page represents the distance from A to B? ____
   b. While the first wave is moving from A to C, the second wave is moving from __ to __.
   c. How must the wave speed after reflection compare with the wave speed before reflection? ____
   d. According to the map, the speed of the ____ is greater than the speed of the ___.
   e. The wavelength after reflection is the distance from ___ to ___ on the map.

6. How can the original frequency be calculated from the originally listed variables? **f_o =** ___

7. How can the frequency of the *reflected* waves be calculated from the listed variables? **f′ =** ___

* 8. Use equations 6 and 7 to create a formula for calculating the car's speed from the two frequencies and the wave speed.

1. Imagine a little bar magnet in otherwise empty space. An ideal compass can detect the magnetic field produced by the bar magnet at practically any distance. If the bar magnet is suddenly flipped over, reversing its poles, the ideal compass is able to detect that change even when it is very far away. Do you think the compass will respond immediately, or will some time be required for the change in magnetic field to be propagated from the magnet to the compass? _______

2. Now imagine an electric dipole. It creates an electric field that extends into all space, so long as there is nothing to interfere. If we flip that dipole over, the electric field should be reversed everywhere. Do you expect that alteration to occur everywhere at the same instant, or do you expect the change to propagate outward at a finite speed like a ripple on a pond? ________

3. With the discovery of Faraday's law we saw that a changing magnetic field always produces an electric field. During the nineteenth century James Clerk Maxwell showed that a changing electric field always produces a magnetic field. (We didn't have time to discover that for ourselves, but it has been verified.) The propagations described in #1 and #2 above are both examples of "electromagnetic waves". Radio waves, microwaves (radar) light, x-rays, and gamma radiation are all examples of electromagnetic waves, differing from each other only in wavelength and frequency. If you want to understand electromagnetic waves, you must study laws that predict the strengths of electric and magnetic fields.

4. As you know, the magnetic field in a solenoid depends upon the current, the number of turns, the dimensions and shape of the solenoid, and also upon a magnetic property of the core material. A given solenoid with a given current will produce a much stronger magnetic field in iron than in air, because iron has a much greater **"magnetic permeability"** than air. Any formula for predicting magnetic fields must contain a symbol representing the magnetic __________ of the medium.

5. The electric field produced by a given distribution of charges is altered if you change the insulating material between them because different insulating materials have different **"permittivity"** values. Any formula for predicting electric field strength must therefore contain a symbol representing the ___________ of the medium.

6. You have discovered that the speed of mechanical waves on a stretched spring or guitar string can be predicted from tension and linear density. You also discovered that the speed of sound waves in air can be calculated from the density and compressibility of the air. In fact, the same formula can predict the speed of sound in any other medium, even the interior of a star. It is also possible to predict the speed of **electromagnetic** waves, starting with electric and magnetic properties of the medium. We expect the speed of electromagnetic waves to dependon the __________ and ___________ of the medium in which they travel.

7. Suppose you and I collect identical samples of some material such as the atmosphere of Mars. In our own laboratories we carefully measure the two properties mentioned at the end of #6. Do you expect our results to agree, or can they differ significantly? ____

8. Suppose the two laboratories mentioned in #7 are on two space ships. Your spacecraft is moving relative to mine, so mine is moving relative to yours. Does that fact alter your answer to 7? ____

9. Instead of testing samples of Martian atmosphere, suppose we choose to test samples of vacuum taken from the dark side of a Martian moon: Will our results agree? ___

10. Is the vacuum just outside your spacecraft different in any way from the Martian Moon vacuum? __

1. Imagine that you and I are in spaceships travelling at great speeds in different directions. We each measure the permittivity and permeability of the vacuum outside of our spacecraft, and we use those results to predict the speed of electromagnetic waves in vacuum. We write down our predictions in standard units and mail them back to Earth. Do you expect the predictions to agree? ____

2. Are all vacuums equivalent? ____ Suppose we each measure the speed of the light from a distant star in the vacuum outside of our respective spacecraft. Do you expect the results to agree? ____

3. Back in Chapter II you decided that the velocity of C relative to B plus the velocity of B relative to A must be equal to the _____ of ___ _____ __ __. Now suppose "C" represents the light wave from a distant star, "B" represents your spacecraft, and "A" represents mine. Can that equation still be valid?

4. Suppose I claim that my spacecraft was at rest when the measurements were made, and that yours was moving. You insist that yours was at rest, and mine was moving. Is there any way to settle the dispute? ____ If so, please describe how to prove that one frame of reference is absolutely at rest.

5. Michelson and Morley did an extremely sensitive experiment in Cleveland in 1887 to detect the motion of the earth relative to the surrounding vacuum. What did we learn from it?

6. Imagine that each spacecraft is accompanied by a vast fleet of invisible "demons" moving along with the craft in fixed formation. The position of each demon relative to the spacecraft is known precisely. Every demon is in radio contact with the ships Demon Control Center, or "DCC". Any event occurring at any location in the fleet is reported immediately to the DCC computer, which records the coordinates of the event and the time of its occurrence. (The DCC computer even compensates for the time required for radio signals to travel from demon to DCC!)

   Your demon fleet overlaps mine, of course. If a flashbulb pops anywhere in the universe, your DCC records the location and time of that event as (X_b, Y_b, Z_b, T_b). My DCC records the location and time of the same event in my coordinate system as (X_a, Y_a, Z_a, T_a). Although it is unlikely that we can ever decide which coordinate system is "correct", it should not be difficult for you to use the four numbers recorded by your DCC to figure out the four numbers recorded by mine, and vice versa.

   a. What additional information is needed in order to accomplish that?

   b. What formulas will you use? For simplicity you may assume that the velocity of B relative to A is parallel to the x-axes of both coordinate systems and that the two origins coincide when $T_a = T_b = 0$. The set of equations for this "coordinate transformation" was first published by Galileo. Most people find it boring because the equations don't tell you anything that you didn't already know. The interesting thing about them is the fact that they *can't be correct*, as will be shown below.

      X_b =
      Y_b =
      Z_b =
      T_b =

7. Consider a light wave travelling outward from a flashbulb. It must travel with uniform speed "c" in every direction away from the flashbulb, because of the uniform properties of the vacuum. Therefore it must form an expanding spherical surface.

   a. After a time interval of "T", the radius of the sphere must be ___.

   b. Suppose I have my demon fleet report the locations of many points on that spherical surface at time "T". With simple geometry I should then be able to locate the center of the sphere, and you should be able to do the same with information obtained from your demon fleet. Describe a procedure with which you can find the geometric center of a sphere or circle, given a few points on the circle.

   c. Each of us must assume that the center point of the expanding light-sphere must remain stationary in our own frame of reference. Also, we are free to choose coordinate systems so that the center of the sphere is on the x-axis. If I ask the demon at the center point if anything has happened there recently, I expect him to report the popping of a flashbulb. You expect a similar report from one of your demons. Do those two "centers" coincide, according to the Galilean transformation? ___

   d. Is there any way to prove that one of the two centers is "correct" and that the other one is "wrong"?

   e. Can one expanding sphere have two different centers? ____

   f. What must we conclude about the Galilean transformation equations? ____