# W O R K

(L-10)

When a body moves under the influence of a *conservative force field*, the amount of work the field does on the body as it moves from one point to another is *path independent*. That is, no matter what path is taken between the two points, the amount of work done by the field is always the same. This lab is designed to verify that claim.

The *conservative force field* we will use in this lab is the force field associated with *gravity*. The two points we will deal with will be exactly *1 vertical meter apart* (because gravity is a constant near the earth's surface, it won't matter whether the points are at .5 meters and 1.5 meters from the ground or 1.5 meters and 2.5 meters from the ground--what is important is that the *net vertical distance* is *one meter*).

Consider the following situation: You apply a force to a frictionless cart on an *incline plane* so that the cart rises a *net* <u>*vertical*</u> *distance* of one meter WITHOUT ACCELERATION (i.e., with constant velocity). In this case, there are only two *work-producing forces* acting on the cart--you and gravity (the *normal force* is perpendicular to the motion and, hence, does no work). Because the cart does *not pick up* or *lose* speed, the NET WORK done must be ZERO (the *work/energy theorem* maintains that if the <u>*change*</u> *of kinetic energy* is zero, the *net work* is zero). This, in turn, means that the work *you do* must be *equal and opposite* the work *gravity* does.

Bottom line: Given a *constant velocity*, if you can determine the work *you* do on the system, you will know how much work *gravity* does on the system. In lab, you will use these ideas to determine the amount of work gravity does on a cart as the cart rises *without acceleration* one vertical meter via three different devices: a dead lift; a pulley system; and an incline plane. Enjoy.

## PROCEDURE--DATA

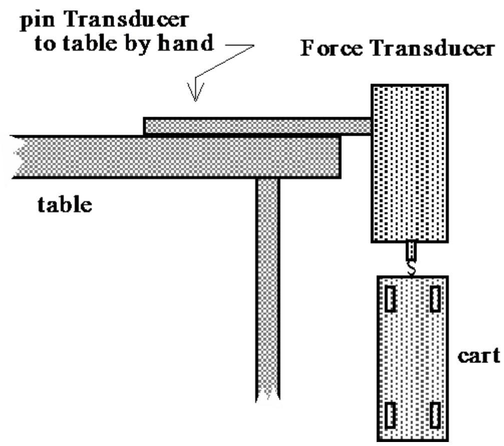
**<u>Part A:</u>** (setup)

**a.)** Connect the FORCE TRANSDUCER to the Lab Pro, then open up the Logger Pro program on your computer. Calibrate the TRANSDUCER.

**i.)** Hold the transducer steady off the table in the position shown in the figure below.

**ii.)** Choose Calibrate from the Experiment menu in Logger Pro and click Calibrate Now. Enter the known value (0 N). Then hang a 500 g mass off the transducer and enter the known value (4.9 N). Then click Keep, and Done.

**b.)** The program will present both a *Force versus Time* graph, a *data table* and a box in the bottom-left corner with big red numbers. That big red number is the force the transducer is registering at the particular instant. YOU WILL TAKE DATA FROM THE *RED NUMBER* ONLY. To check whether your calibration has worked, when you remove the 500 g mass, it should read close to 0.




**Part B:** (dead lift)

**c.)** At some point, measure the mass of the CART and the mass of the secondary pulley you will be using in the double Atwood machine (you will be using BOTH as your mass in ALL set-ups).

**d.)** You want to determine the amount of force *you must apply* to lift the cart+pulley *one vertical meter without acceleration*. THE FORCE WILL BE THE SAME NO MATTER WHAT THE VELOCITY IS AS LONG AS THE VELOCITY IS CONSTANT (i.e., a = 0). One way to do this is to put the cart on the floor and proceed to raise it upward with as close to a *constant velocity* as possible. A more clever way is to notice that ZERO VELOCITY is a constant velocity and simply measure the force required to hold the cart motionless (the *force* will be the same--IF THIS ISN'T CLEAR, ASK ABOUT IT!).

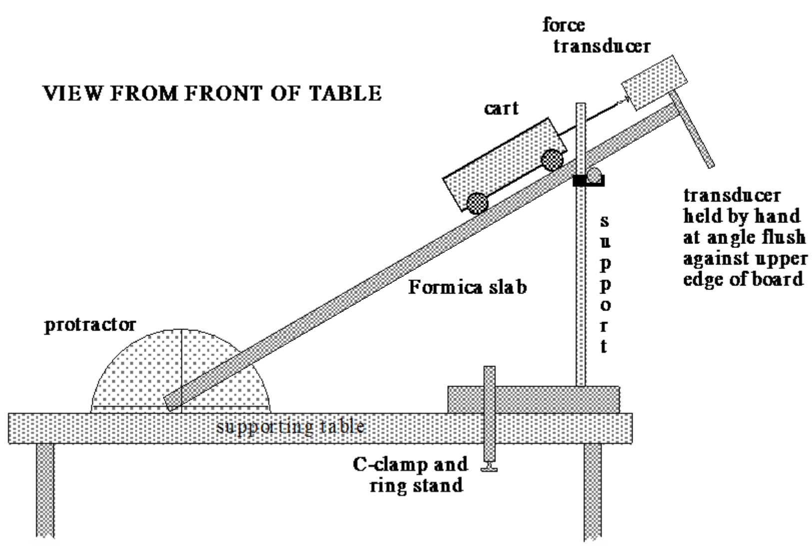
Following along with this, use the table to support the TRANSDUCER and hang the cart+pulley from the TRANSDUCER'S ARM (see the sketch above).

--When the cart+pulley are hanging steady, record the force.

**Part C:** (the incline plane)

**e.)** Build an *incline plane*. The angle should be no more than $25^o$. Measure and record your angle (you can use a protractor or an iPhone).

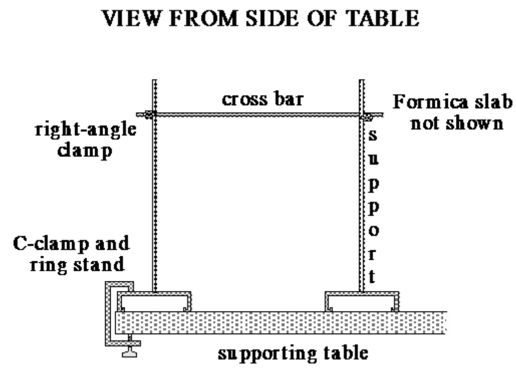
**f.)** With the force transducer in position on



the incline, ZERO the transducer (the computer command is on the EXPERIMENT pull-down).

--Be sure that the STRING connecting the TRANSDUCER'S ARM and the cart+pulley is parallel to the incline.

--Support the TRANSDUCER against the uppermost edge of the incline board with the cart attached to the ARM (see sketch).



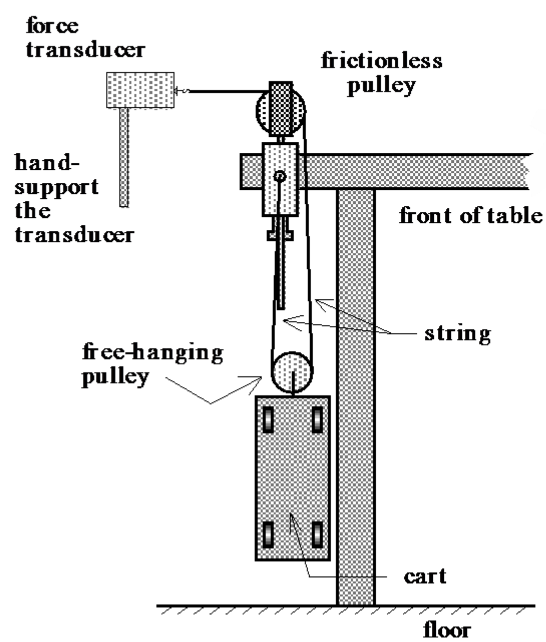

--Use the TRANSDUCER to determine the *force* required to hold the cart and secondary pulley *motionless* on the incline. Record that force.

**g.)** *Before leaving lab*, determine exactly how far you would have to apply your force to the cart up the incline if the cart were to rise one vertical meter. You will not be able to actually effect this motion because the incline will not be long enough, but figure out how far up the incline you *would* have had to have pulled if you *could* have done so. You'll need to BLURB this in your write-up (explain your logic and your calculation).

If this is confusing, discuss it with your partner.

**Part D:** (moment of truth)

**h.)** Because it is important that your force data be consistent, it would be nice to know that you haven't inadvertently messed up the TRANSDUCER'S CALIBRATION during this part of the lab. To check, take a deep breath, say a short prayer if you know one, then: hang the force transducer in the position you used during calibration and ZERO the transducer. Hang a 500 gram mass off the transducer and see if the force reading you get is within 0.1 newtons of the value of 4.9 newtons. If it is, say "Hallelujah Brother (or Sister)" and continue. If your cart's weight-reading is off by more than 0.1 newtons, call me. You will probably have to re-calibrate and do the *preceding sections* over again.




**Part E:** (double Atwood Machine)

**i.)** Construct a DOUBLE ATWOOD MACHINE by attaching the cart to a freely hanging pulley as shown in the sketch to the right (you need a long string with loops on both ends and a free-hanging pulley to make this setup). Use the TRANSDUCER to determine the force *you would have to exert* if the device were to raise the cart *one vertical meter without acceleration*. Record that measurement.

**j.)** Assuming your setup has enough string to accommodate such motion, how far would YOU have to pull the string to make the cart rise one vertical meter (if you say "one meter," think again)? Again, you'll need to BLURB this in your write-up (explain your logic and your calculation).

If this is confusing, discuss it with your partner.

**Part F:** (moment of truth . . . again)

**k.)** Recheck your calibration. If the transducer's reading is acceptable, say "Hallelujah Brother (or Sister)" for the last time, take down your device, and scoot. If it is off by more than 0.1 newtons, re-calibrate and do the preceding section over again. (You won't have to redo *Section C* because, presumably, you checked and found the calibration to be OK after you did that part).

## CALCULATIONS

**1.)** Using the *computer measured force* you applied to the cart and the appropriate distance quantity, use the definition of *work* to determine the amount of work YOU had to do to raise the cart *one vertical meter* without acceleration using *a dead lift*. SHOW YOUR EQUATIONS ALGEBRAICALLY FIRST, then put in the numbers and present a boxed numerical answer (don't forget *units*).

**2.)** Using the *computer measured force* you applied to the cart and the appropriate distance quantity, use the definition of *work* to determine the amount of work YOU had to do to raise the cart *one vertical meter* without acceleration using *an incline plane*. SHOW YOUR EQUATIONS ALGEBRAICALLY FIRST, then put in the numbers and present a boxed numerical answer (don't forget *units*).

**3.)** Using the *computer measured force* you applied to the cart and the appropriate distance quantity, use the definition of *work* to determine the amount of work YOU had to do to raise the cart *one vertical meter* without acceleration using *a double Atwood Machine*. SHOW YOUR EQUATIONS

ALGEBRAICALLY FIRST, then put in the numbers and present a boxed numerical answer (don't forget *units*).

**4.)** The solutions presented in Calculations 1, 2, and 3 represent the amount of work *YOU* would have had to have done on the cart if it were to have risen one vertical meter without acceleration. What is significant is that this is also numerically equal to the amount of work *GRAVITY* would have done as the cart rose. With that in mind:

**a.)** Take the two work values that were the furthest apart and find the % difference between the two.

Note: unlike a % error comparison, which compares an experimental value to a theoretical or expected value, % difference allows to compare two independent measurements. For this type of calculation, use the equation:

$$\% \, difference = \frac{|value\ 1 - value\ 2|}{average\ of\ both\ values} x100$$

**b.)** Comment concerning the truth of the statement: "The WORK DONE by a *conservative force field* (*gravity*, in this case) on a body moving from one point to another in the field is *path independent*."

## <u>QUESTIONS</u>

**I.)** Let's assume you have a 2000 pound car you want to lift one vertical meter off the ground. Additionally, assume you have a humongous double Atwood Machine similar in design to the one you used in lab, a car-strength incline plane set at $15^o$, and the personal strength needed to dead lift the car if necessary (can you say, "gooooorilla?").

**a.)** In effecting the pick-up, which technique would you expect would require the *least amount of work* in a *real world* setting? Put another way, I want you to use your head (forget your experimental results) and decide which technique would, <u>in the real world</u>, inherently end up requiring the *least amount of WORK* to accomplish the task. Explain your reasoning.

**b.)** Which technique would make the job *easiest* in the sense of requiring the *least amount of FORCE* to accomplish the task? Explain your reasoning. (No, you *can't* DRIVE the car up the incline.)