Impulse and Linear Momentum

Our central tool in the study of mechanics is *Newton's Second Law* in its ultimate formulation:

$$\frac{d\vec{p}}{dt} = \vec{F}^{net}$$

We may write this equivalently, in its "*Newtonian horizontal form*"

$$d\vec{p} = \vec{F}^{net}\, dt$$

What it's telling us is that, when a force is applied to an object, what is really happening is that momentum is being transferred … moment by moment. Force is now perceived – as what it really is - a <u>secondary quantity</u> … that is to be understood as *"the rate of transfer of momentum"*. That is, "force" is just a descriptor aiding our tracking of the really important thing … the "conserved thing" … momentum. Force is now to be understood as a "rate of transfer" of momentum. In this sense it's like "*Power*" which is just the "rate of transfer" of energy.

Since we generally inspect the world in finite amounts of time, we may conveniently integrate this latter equation to obtain:

$$\overrightarrow{p_f} - \overrightarrow{p_i} = \Delta\vec{p} = \int_i^f \vec{F}^{net}\, dt$$

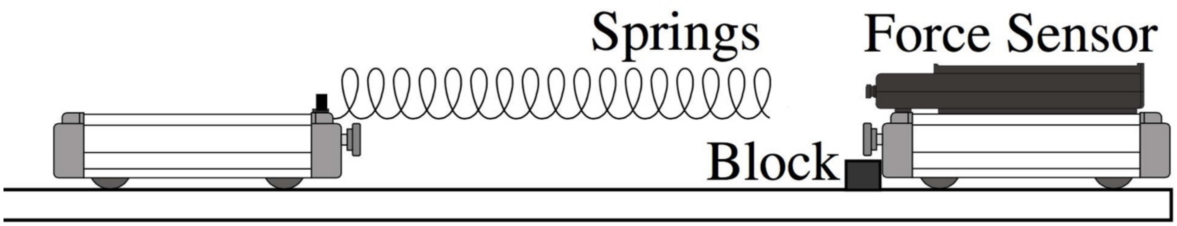
The net change in momentum experienced by any object is then seen to be just the time integral of the net applied force from the initial moment to the final moment in time. This time-integrated force is called "Impulse" and carries its own dedicated letter: $\vec{J}$.

The Lab

In this lab we send in a cart to collide with a stationary cart equipped with a force sensor. This allows us to actually see what the collision is like. It generally happens very fast – and we need fast electronics to follow the action. The force generally appears as a ragged "spike" sort of graph. Since, in this case, it's pushing leftwards it will record as a negative number. The time integral giving the "area" under this spike is the impulse and can be added up by the computer program. Since we can also track the incoming and leaving velocities of the cart and since:

$$\vec{p} = m\vec{v}$$

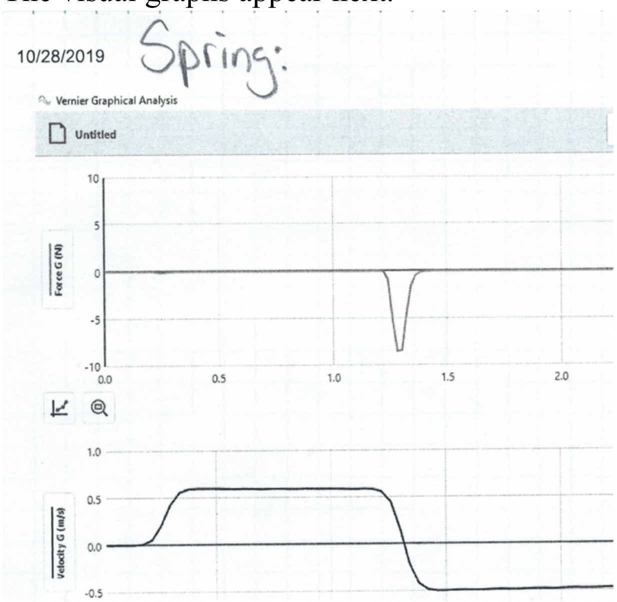
… we can independently compute both the right and left sides of the impulse equation and check whether they, indeed, agree as we predict.

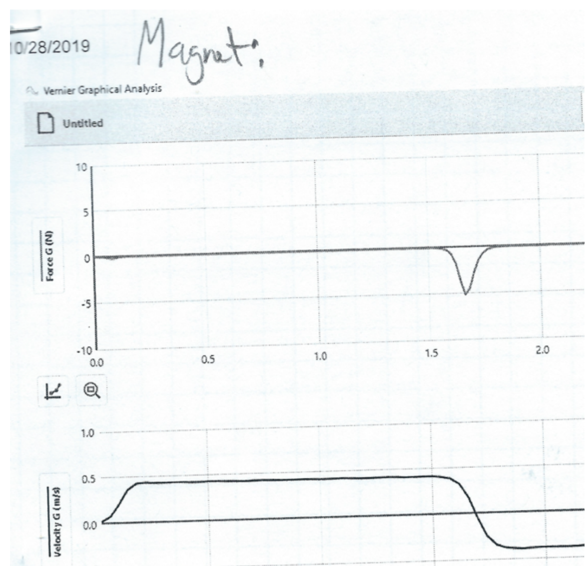


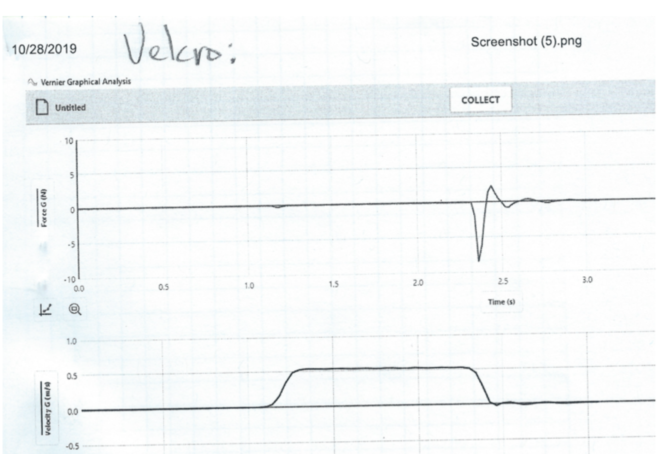
The Graphs:

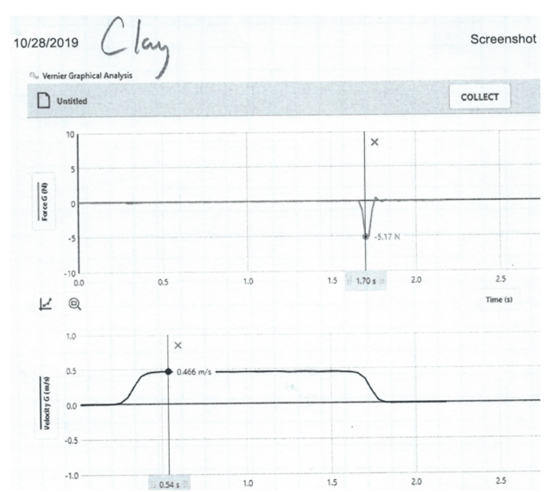
We try four collisions types. 1) A Spring-force, 2) A magnetic-force, 3) A sticky chunk of clay, 4) A Velcro surface. The first two are nearly elastic while the last two are clearly totally ineleastic. A fifth "reduced force" attempt follows last.

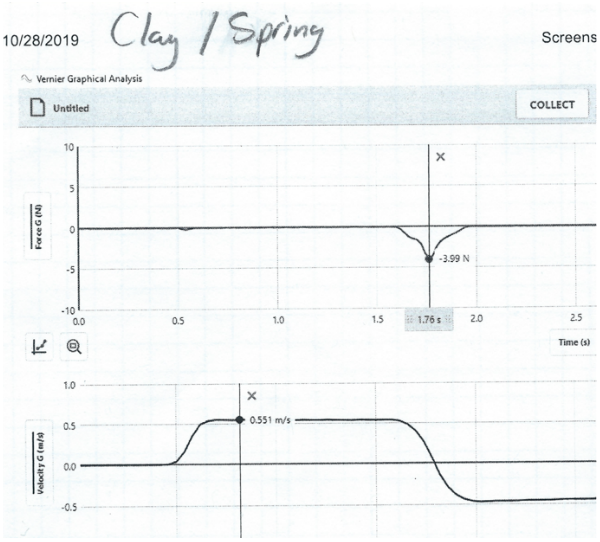
The visual graphs appear next.











In each case, the force is portrayed first above with the velocity just below. Notice that the "spike" appears just above the rapid change in velocity.

The Data:

Next, we present actual data taken in that lab period (though not from the graphs portrayed).

Cart Mass = .7858 kg

Collision-type:	$V_{initial}$ (m/s +/- .001)	V_{final} (m/s +/- .001)	**Impulse (area)** (N•sec)
Spring	0.442	-0.394	-0.657
Magnetic	0.384	-0.275	-0.463
Velcro	0.406	0.0	-0.332
Clay	0.400	0.0	-0.311

The fifth graph was an attempt to "minimize the force" … while retaining the same impulse. What should the "force-time" graph look like? How does one really effect this in practice – say, in automobile design?