SDI LAB #2. NEWTON'S SECOND LAW*

NAME _____   _____   _____ _____ _____
<div align="center">Last (Print Clearly)   First (Print Clearly)   ID Number</div>

LAB SECTION _____LAB TABLE POSITION_____

And from my pillow, looking forth by light
Of moon or favouring stars, I could behold
The antechapel where the statue stood

Of Newton, with his prism and silent face,
The marble index of a mind for ever
Voyaging through strange seas of Thought, alone.
William Wordsworth *(1770 - 1850)*

_____-

I. INTRODUCTION

   Newton, virtually alone in his original research, was united with the scientific community after publication of his *Principia* in 1687. In this lab you join him in his "strange seas of thought" and continue to develop a physical understanding of Newton's Laws by actively applying them to simple mechanics experiments. Here you concentrate on Newton's Second Law (N2), $\vec{\mathbf{F}}_{\text{net on body}} = m_{\text{body}}\vec{\mathbf{a}}_{\text{body}}$. During the course of the lab it may be helpful for you to refer to the three Newton's Law diagrams hanging above your table (N1 and N3 are also included as the last page of SDI Lab #1, N2 in included as the last page of this manual).

   A. OBJECTIVES
      1. To devise (Pre-Lab Assignment for SDI #2) *operational* definitions for certain kinematic terms: position, instantaneous position, displacement, time, instant of time, clock reading, continuous motion, time interval, uniform velocity, instantaneous velocity, uniform acceleration, instantaneous acceleration, inertia, inertial reference frame.

      2. To understand Newton's second law as applied to certain simple mechanics experiments:
         a. velocity and acceleration in the nearly frictionless motion of dry-ice blocks on glass,
         b. vertical toss of a ball,
         c. projectile motion of a ball,
         d. juggling of six balls,
         e. motion of a pendulum bob,
         f. vertical fall of a steel ball and paper coffee filter,
         g. a kid in a truck (revisited).
      3. To consider various "thought" experiments before performing the real experiments.
      4. To consider the relationship between experiment and theory.

 B. HOW TO PREPARE FOR THIS LAB
    1. **STUDY** this manual **BEFORE** coming to the lab.
    2. Review previous SDI labs: #0.1, *Frames of Reference, Position, and Vectors* (including the Ground Rules in Sec. C); #0.2, *Introduction to Kinematics*; #1, *Newton's First and Third Laws*, especially Appendix A. "Drawing Acceleration Vectors in Time Sequential Snapshot Sketches."
    3. **Complete the Pre-lab Assignment "Operational Definitions of Kinematic Terms"** *which must be submitted at the START of this lab.*
    4. Review Chapter 4, "Motion and Force: Dynamics," and Chap. 5 "Circular Motion; Gravitation" in the course text *Physics*, 4th ed. by Douglas Giancoli (or similar material in whatever text you are using).
    5. Review Giancoli's sections on sketches and diagrams, the crucial first step in problem solving, p. 29, 54, 62, 130, 141, 157, 205, 231 (or similar material in whatever text you are using). This lab should assist you in learning to draw meaningful sketches, thereby helping you to solve the physics problems in exams and homework.
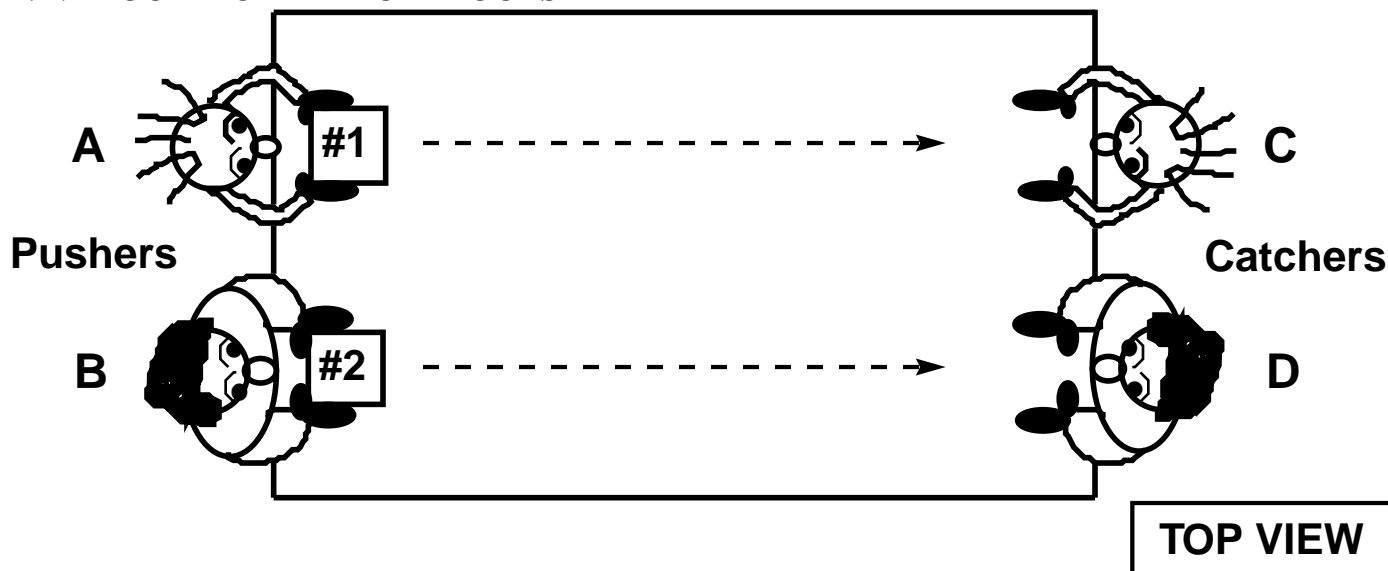
II. VELOCITY OF DRY ICE BLOCKS

Fig. 1. Students wearing protective gloves push dry-ice blocks on a glass-top table.
Weak-student A weakly pushes Block #1 to weak-student C.
Strong-student B strongly pushes Block #2 to strong-student D.

A. A *THOUGHT* EXPERIMENT

Imagine the initial conditions of Fig. 1. You and your lab partners have *donned protective gloves*, placed two dry-ice blocks *of the same weight* ($\approx$ 50 lb, hence masses of $\approx$ 23 kg) *AT REST* on a large ($\approx 42 \times 72$-inch) plate of glass resting on a lab table (with a perimeter fence to retain the dry ice), and positioned yourselves as shown in Fig. 1.

Suppose weak-student A gives Block #1 a "weak" push (impulsive force) so that Block #1 moves relatively slowly towards weak-student C. When Block #1 is about 1/4 of the way across the table, strong-student B gives Block #2 a "strong" push so that Block #2 moves relatively rapidly towards strong-student D. **Suppose that Block #2 *passes* Block #1**.

1. Considering only the motion of Blocks #1 and #2 as they move across the table and *when they are NOT in contact with students' hands*, would you *predict* that for this motion the **velocities** of the two blocks are ever equal? {Y, N, U, NOT} Can you explain your prediction? {Y, N, U, NOT}

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B. THE *REAL* EXPERIMENT

1. Conduct the above experiment several times. In the space below and on the next page, draw three TOP VIEW snapshot sketches, all depicting the observed motion when the blocks are NOT in contact with the students' hands:

Snapshot No.	Block No.	Position of Block
1	1	1/4 of the way across the table, ahead of Block #2
	2	just after leaving strong-student B's hands, behind Block #1
2	1	same x position as Block # 2
	2	same x position as Block #1, about to pass Block #1
3	1	behind Block #2
	2	just before contacting strong-student D's hands, ahead of Block #1

Show **velocity** vectors on Blocks #1 and #2. Show **acceleration** vectors if you think they exist. Show HORIZONTAL **force** vectors if you think they exist. [You need not show vertical forces, since in a TOP VIEW they show up only as encircled dots ☉ (out of the page) or encircled crosses ⊗ (into the page).] For clarity show the entire table and both blocks in each snapshot. Take the black borders of the quadrille-ruled areas to be the edges of the tables. The initial and final positions of the blocks are shown in outline. The vertical lines are the **S**tart, **R**elease, and **F**inish lines. Both blocks move along x-axes as shown.
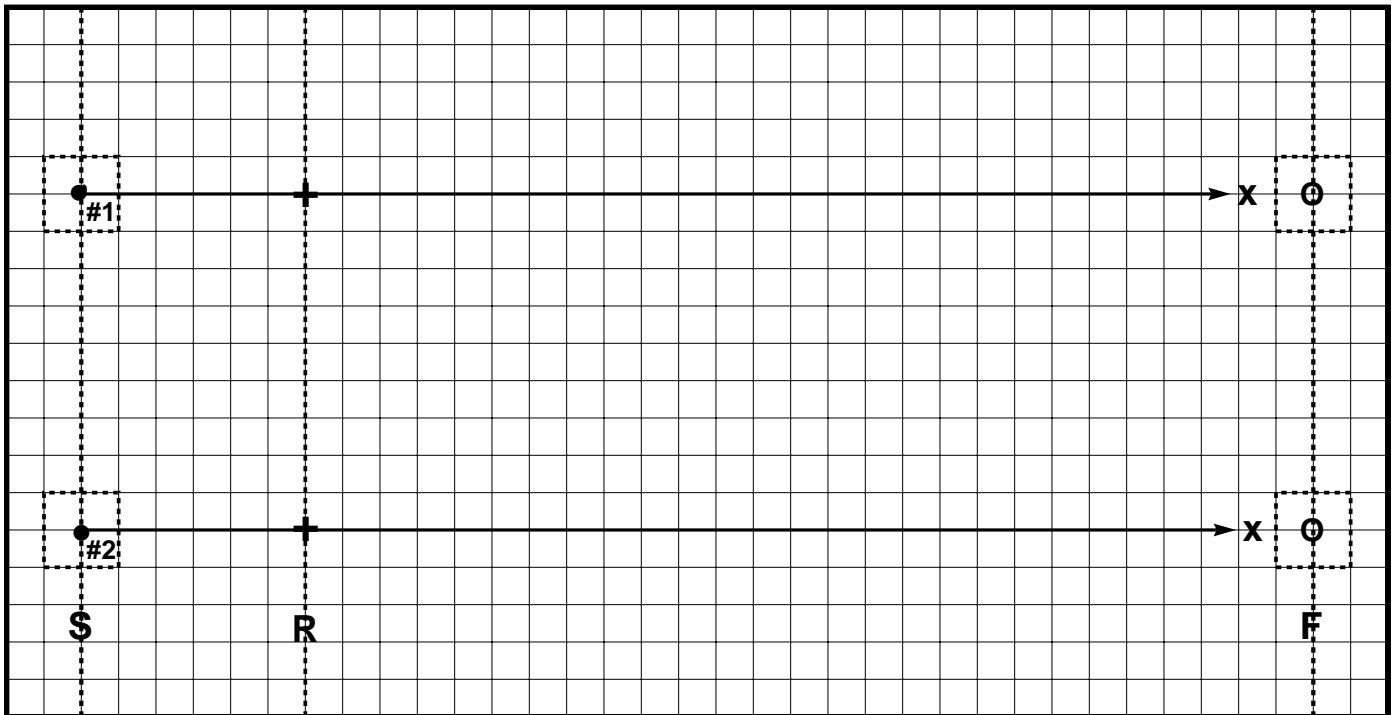
SNAPSHOT #1: Block #1 is 1/4 of the way across the table, block #2 has just left strong-student B's hands.
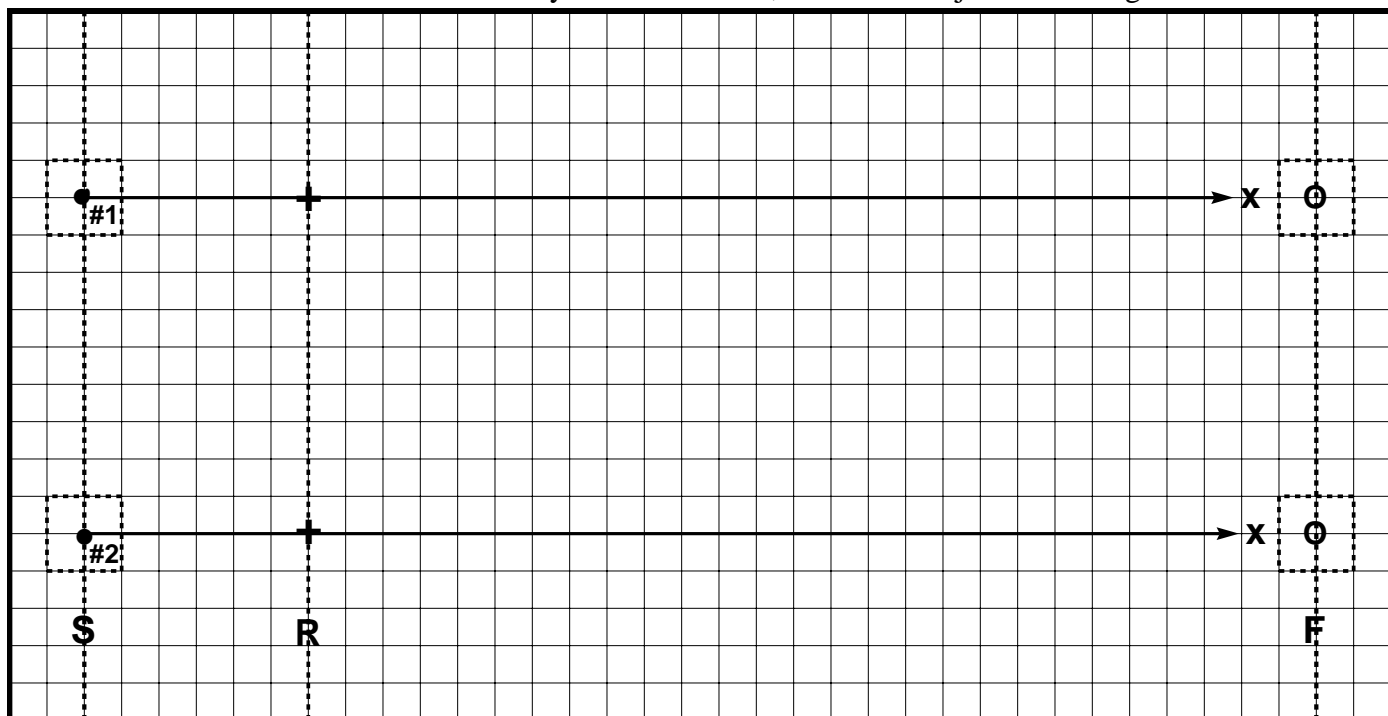
SNAPSHOT #2: Block #2 and block #1 in the same x position. Block #2 is about to pass block #1.
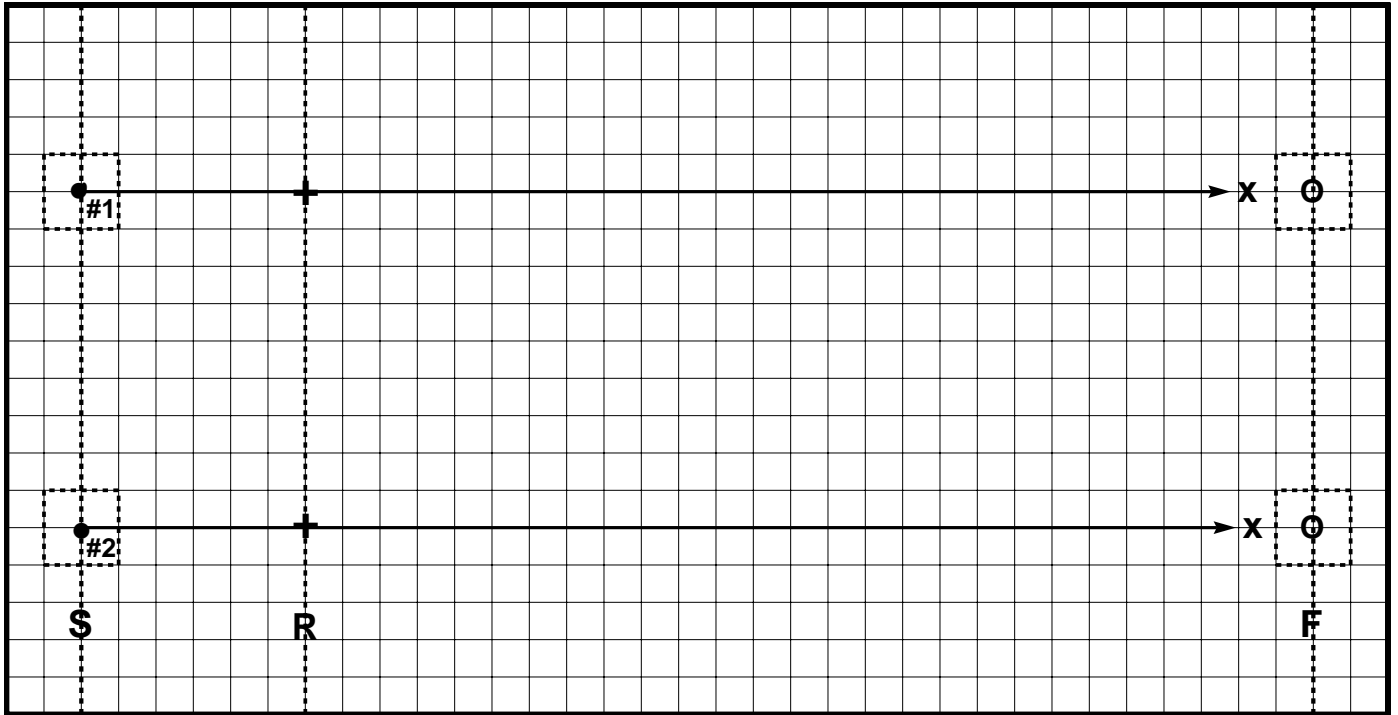
SNAPSHOT #3: Block #2 is just about to contact catcher D's hands. Block #2 has passed block #1.

3. Considering the observed motion as depicted in the 3 snapshot sketches above, are the **velocities** of the two blocks ever equal when the blocks are not in contact with the students hands? {Y, N, U, NOT} Is your prediction of part "A1" above confirmed? {Y, N, U, NOT}

4. Are the above 3 sketches in accord with Newton's second law (N2), $\vec{F}_{\text{net on body}} = m_{\text{body}}\,\vec{a}_{\text{body}}$? {Y, N, U, NOT}

## III. ACCELERATION OF DRY-ICE BLOCKS
A. A *THOUGHT* EXPERIMENT

Imagine the same initial conditions as in Fig. 1 with the blocks *at rest*. But now students A and B push their blocks *simultaneously*. As before, weak-student A pushes her/his block weakly and strong-student B pushes her/his block strongly. Suppose both students apply forces starting at time $t = 0$ which are nearly constant in time *over the **same** short time span* τ (i.e., for $0 \leq t \leq \tau$, note that " $0 \leq t \leq \tau$" means "t equal to or greater than 0 and equal to or less than τ"), the only difference being that strong-student B applies the larger force. Note that the blocks are released at the same time $t = \tau$, but *not* at the same distance from the starting line. Consider the motion of Blocks #1 and #2 over the same ***time interval* T** *from* **t = 0** *until just before Block #2 makes contact with strong-student D's hands.* Please note that "forces starting at $t = 0$" means that the forces *do exist* at $t = 0$.

1. If a net **force** acts on the block at $t = 0$ when the block is at rest, does an **acceleration** exist at $t = 0$? {Y, N, U, NOT}

2. Draw a *graph* of the force F vs time t for the two blocks over the time interval T. Use a solid ***red*** line (————) labeled "Strong" for the strong force and a dashed ***red*** line (– – – –) labeled "Weak" for the weak force. NOTE: The t-axis of the graph below is labeled to show the times t = 0 (initial application of forces to the blocks), t = τ (forces removed from blocks), and t = T (just before strongly pushed Block #2 makes contact with strong-student D's hands). We shall assume that forces build up near t = 0 and fall near t = τ over intervals of time so small as to be invisible on the scale of the drawing.

FORCES **F** APPLIED TO THE BLOCKS BY THE STRONG AND WEAK STUDENTS vs TIME
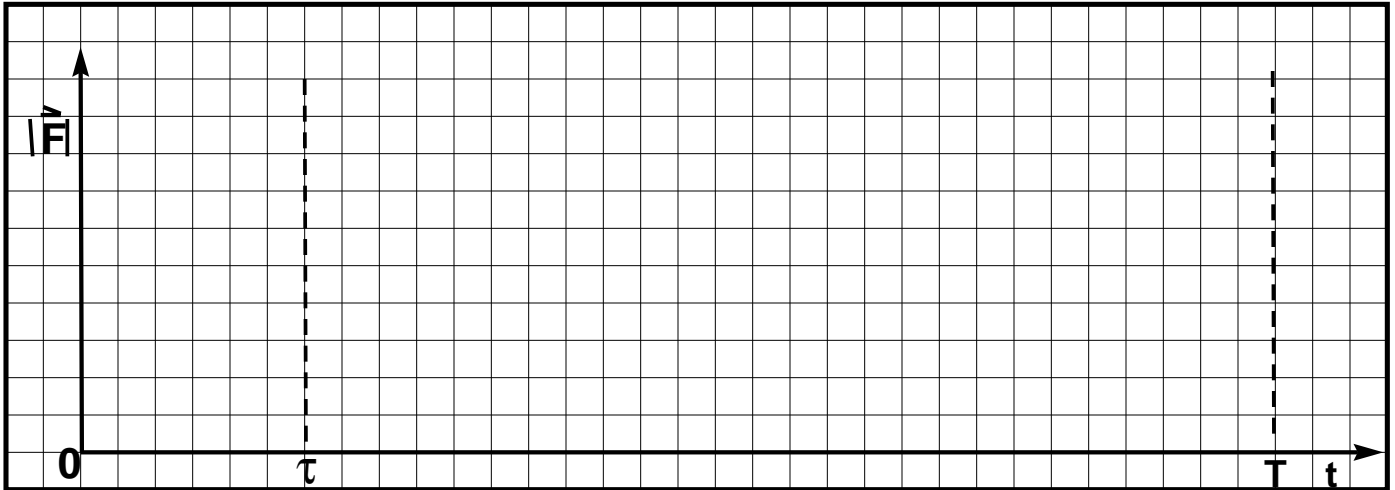
3. Considering the above graph, would you *predict* that the **accelerations** of the two blocks are ever equal at any clock reading during the time interval T (i.e., for $0 \le t \le T \equiv$ time t equal to or greater than 0 and also equal to or less than T) ? {Y, N, U, NOT}

4. Would you *predict* that the **velocities** of the two blocks are ever equal at any clock reading during the time interval T (i.e., for $0 \le t \le T$) ? {Y, N, U, NOT}

5. Would you *predict* that the **displacements** of the two blocks are ever equal at any clock reading during the time interval T (i.e., for $0 \le t \le T$) ? {Y, N, U, NOT}

B. THE *REAL* EXPERIMENT

1. Conduct the above experiment several times. In the space below sketch five TOP VIEW snapshot sketches depicting the observed motion:

| Snapshot #.	Block #	Time	Condition of Block
1	1	$t_1 = 0$	block at rest, force applied at this instant by A's hands
	2	"	block at rest, force applied at this instant by B's hands
2	1	$0 < t_2 < \tau$	still in contact with A's hands
	2	"	still in contact with B's hands
3	1	$t_3 = \tau - \varepsilon$	tiny interval ε just before leaving contact with A's hands at $t = \tau$
	2	"	tiny interval ε just before leaving contact with B's hands at $t = \tau$
4	1	$\tau < t_4 < T$	after leaving contact with A's hands
	2	"	after leaving contact with B's hands
5	1	$t_5 = T$	before contacting C's hands
	2	"	just before contacting D's hands

Show **velocity** vectors on Blocks #1 and #2. Show **acceleration** vectors if you think they exist. Show HORIZONTAL **force** vectors if you think they exist. As before (a) take the black borders of the quadrille-ruled areas to be the edges of the tables; (b) the initial and final positions of the blocks are shown in outline; (c) both blocks move along x-axes as shown; (d) the vertical lines S and F are the Start and Finish lines.

__Take the vertical line R to be the Release line for Block #2 only__. The release line for Block #1 will be at (encircle one) smaller, the same, or larger displacement x than that for Block #2 ? Explain.
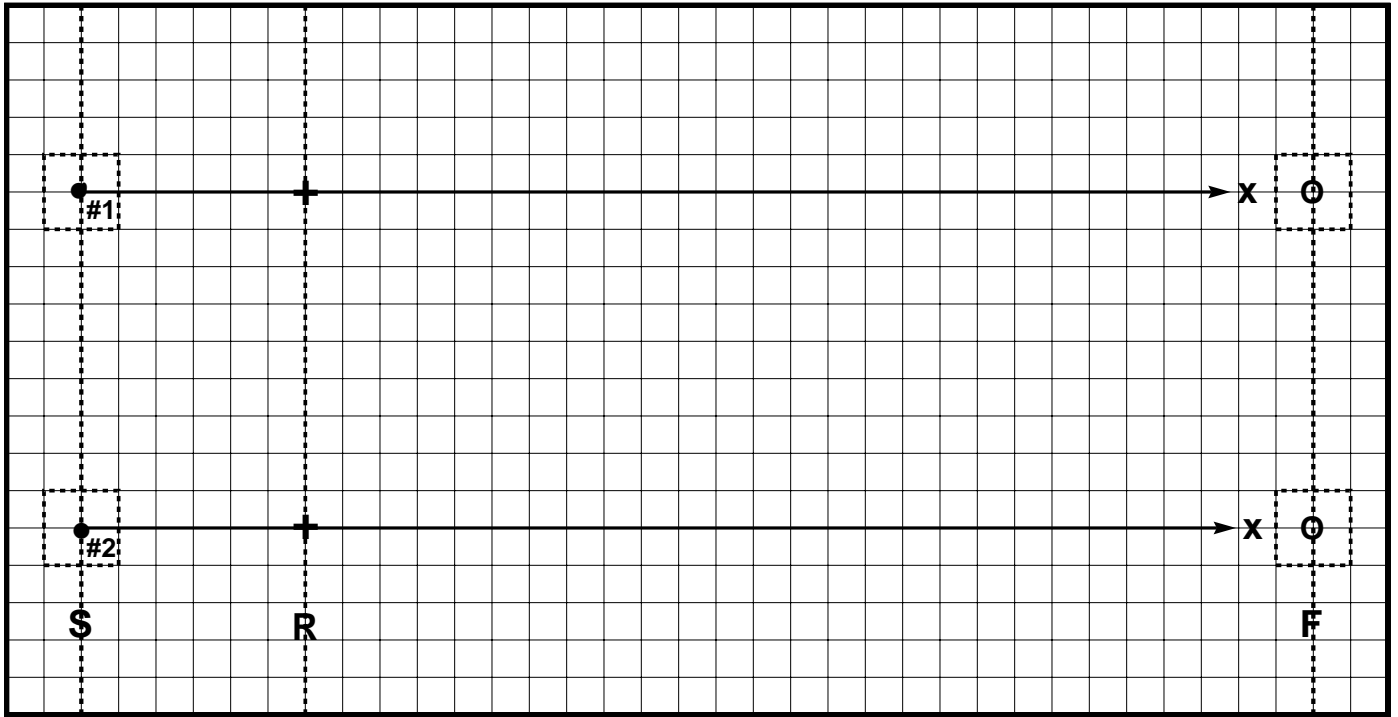
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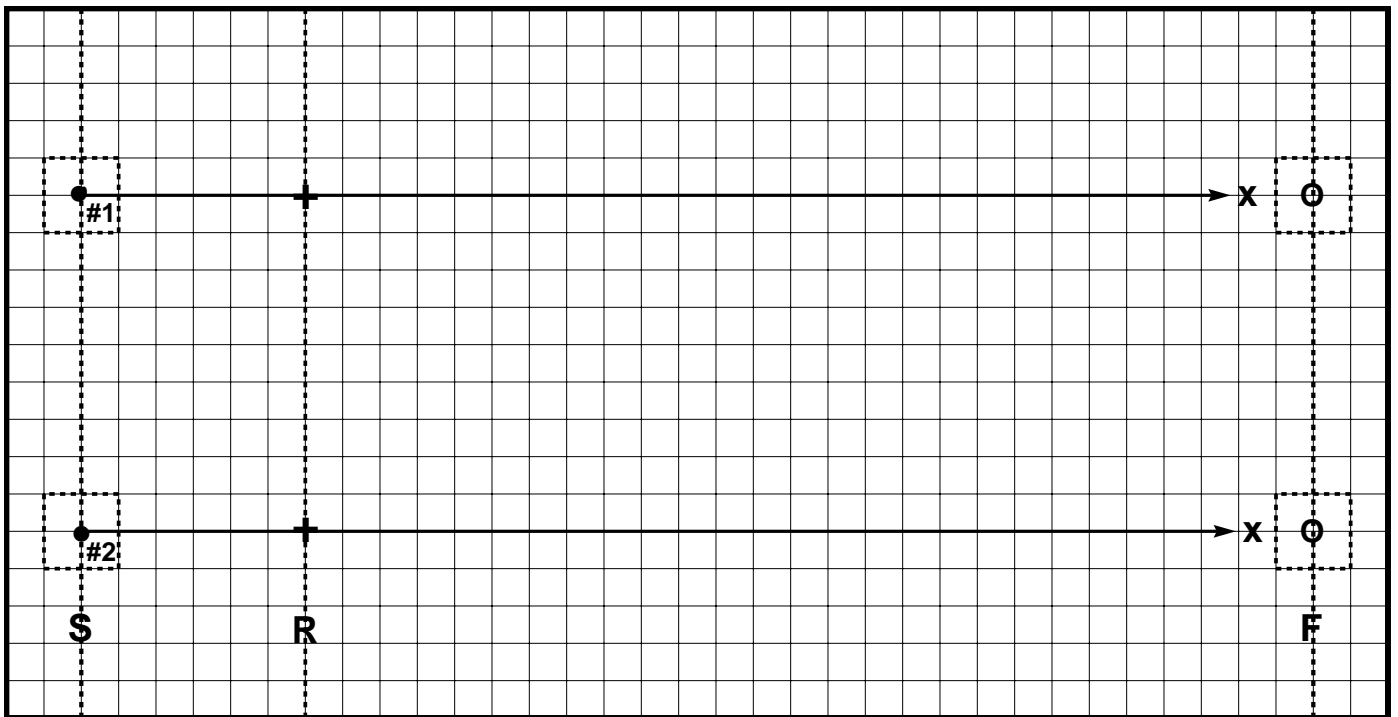SNAPSHOT #1: Time $t_1 = 0$. Both block #1 and #2 *at rest*. Forces on both blocks exist at t = 0.
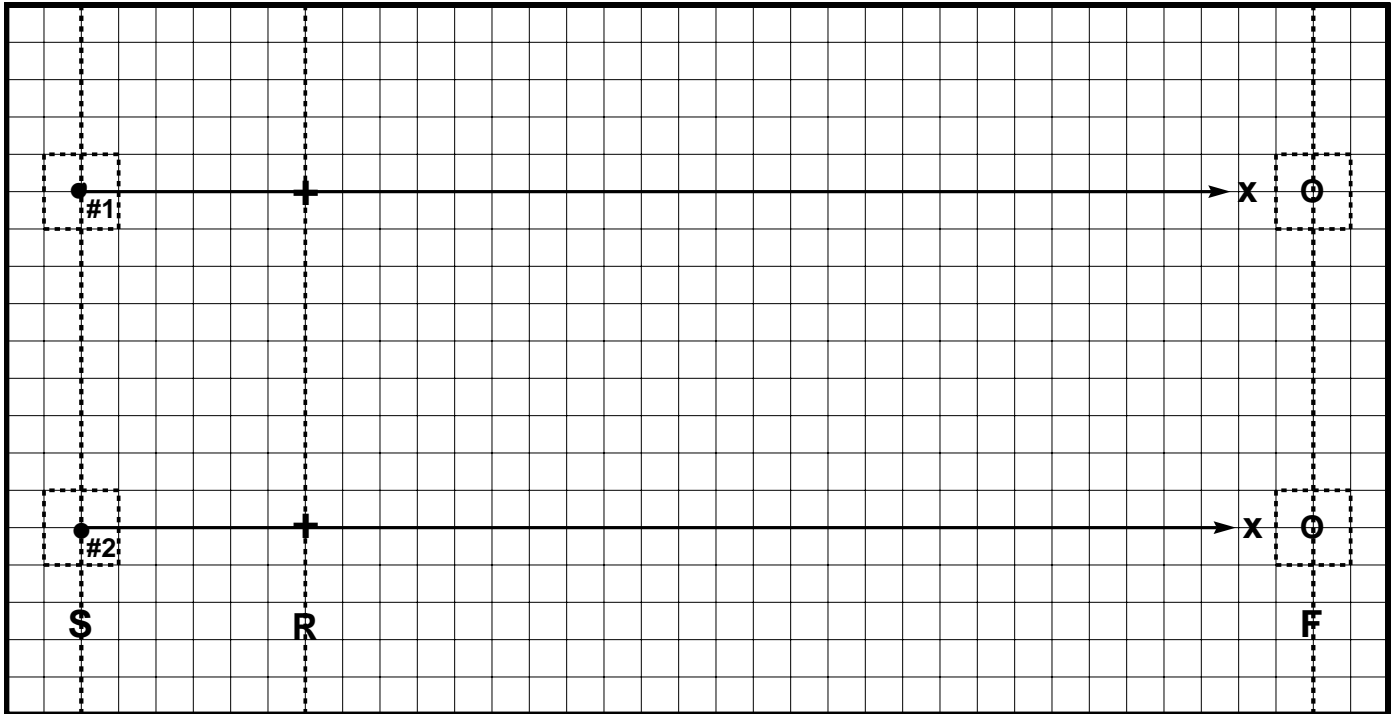
SNAPSHOT #2: Time $0 < t_2 < \tau$. Block #1 still being pushed by A. Block #2 still being pushed by B.
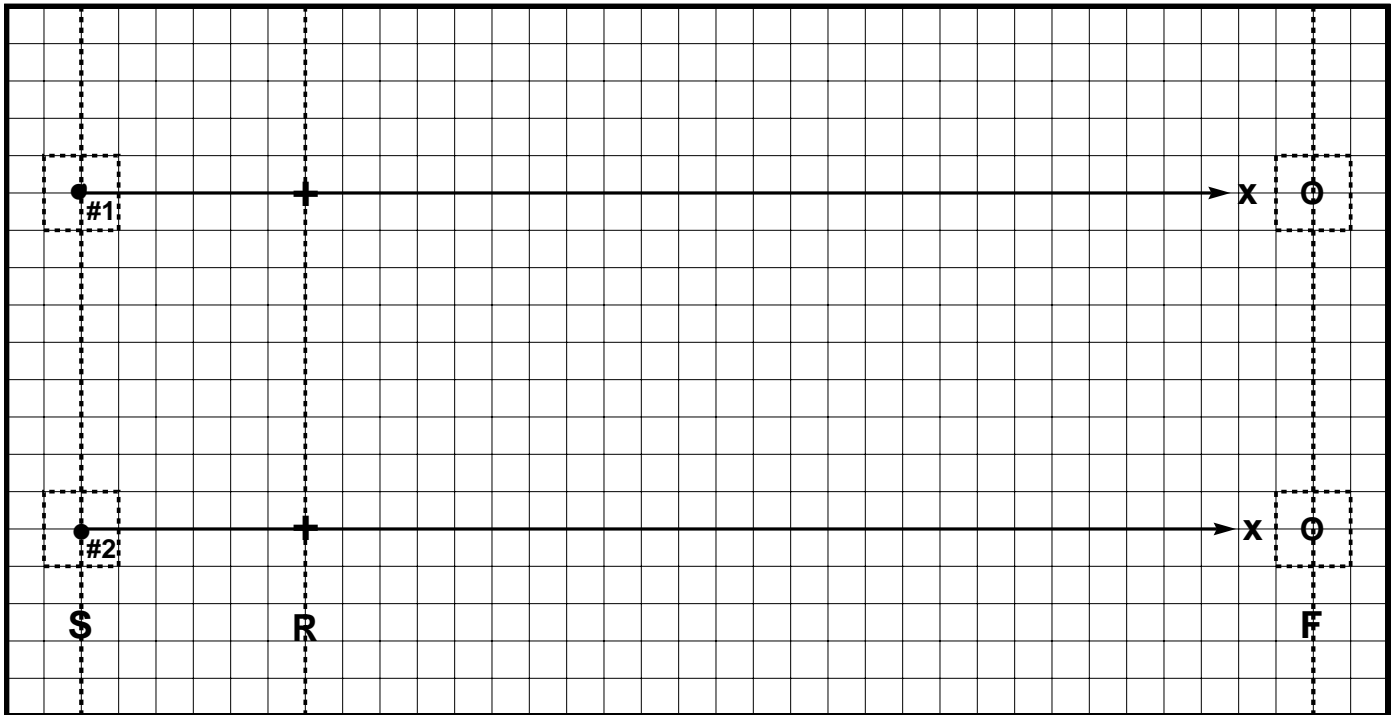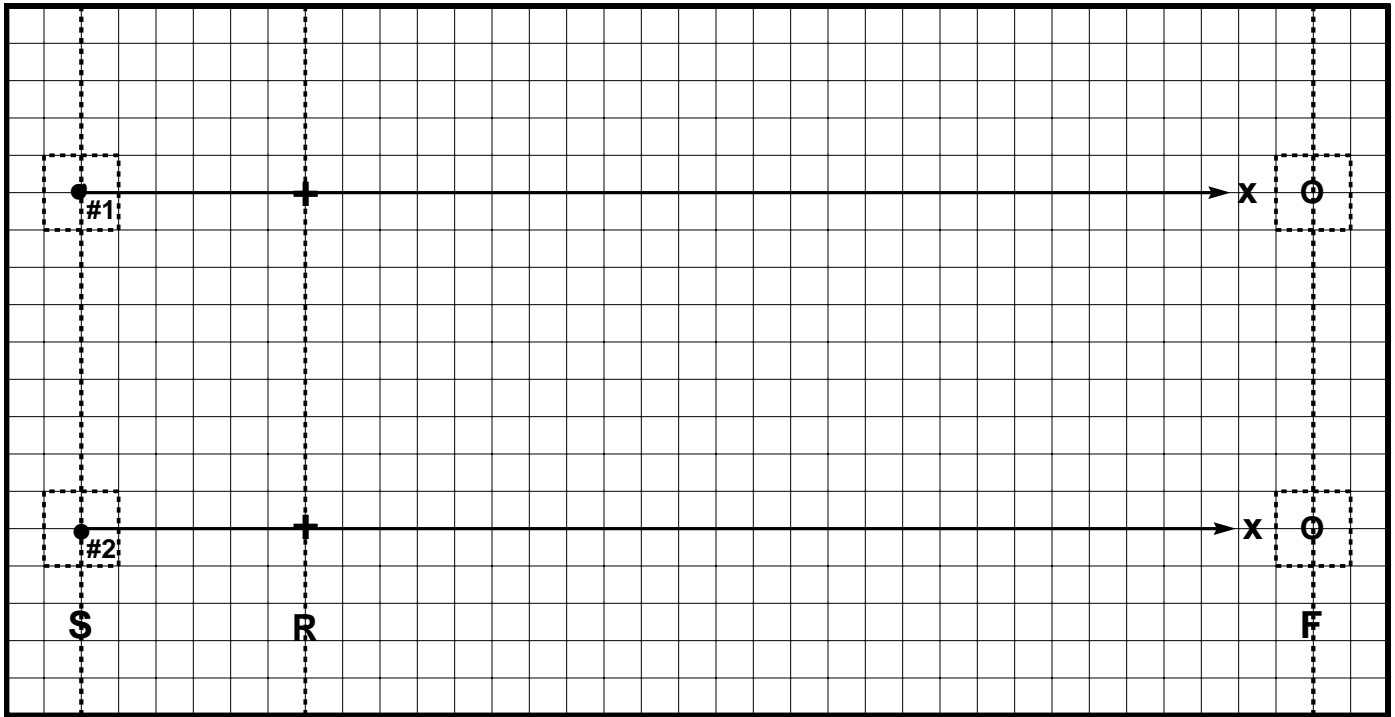
SNAPSHOT #3: Time $t_3 = \tau - \varepsilon$, Block #1 *just* before leaving A's hands. Block #2 *just* before leaving B's hands.

SNAPSHOT #4: Time $\tau < t_4 < T$, Block #1 after leaving A's hands. Block #2 after leaving B's hands.

SNAPSHOT #5: Time $t_5 = T$,   Block #1 before contact with C's hands. Block #2 *just* before contact with
D's hands.

2. Are the above snapshot sketches 1 - 3 in accord with N2, $\vec{F}_{\text{net on body}} = m_{\text{body}}\vec{a}_{\text{body}}$?
{Y, N, U, NOT}

3. In the snapshot sketches 1 - 3 does the strongly pushed block get progressively further ahead of
the weakly pushed block? {Y, N, U, NOT}

4. In the snapshot sketches 1 - 3, do the ratios of the lengths of the $\vec{\mathbf{F}}$ and $\vec{\mathbf{a}}$ vectors for any one block remain constant? {Y, N, U, NOT} What does this ratio represent?
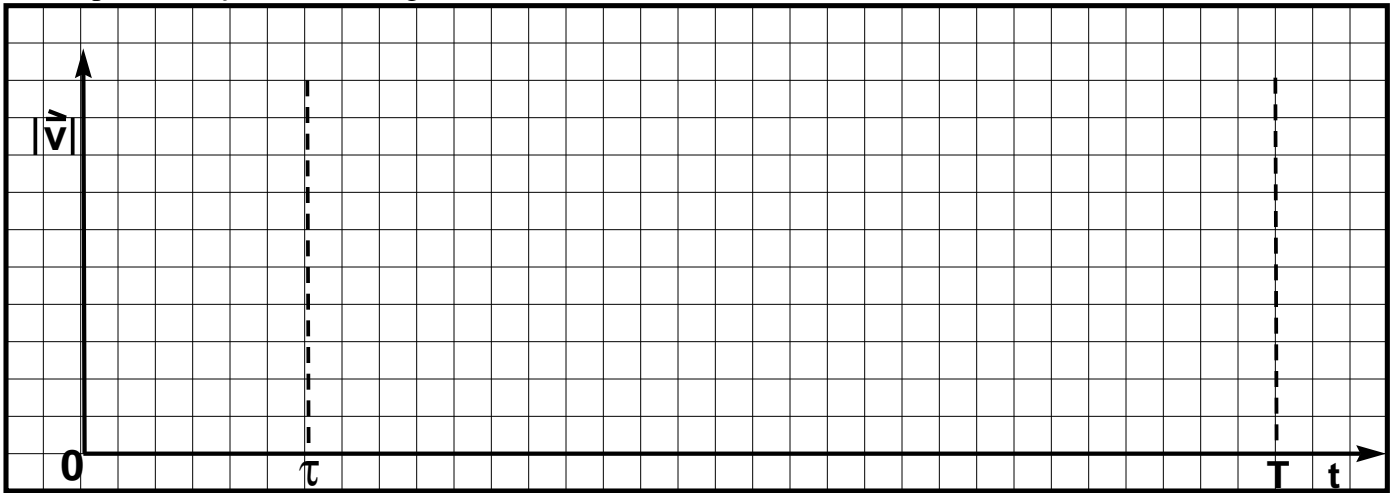
5. Are the above snapshot sketches 4, 5 in accord with N2, $\vec{\mathbf{F}}_{\text{net on body}} = m_{\text{body}} \vec{\mathbf{a}}_{\text{body}}$? {Y, N, U, NOT}

6. Considering the observed motion as depicted in the 5 snapshot sketches above, ***graph*** the kinematic parameters of the motion vs time as indicated below **for the time interval T** (i.e., for $0 \le t \le$ T). The t-axes of the graphs on the next page are labeled to show the times t = 0 (initial application of forces to the blocks), t = τ (forces removed from blocks), and t = T (just before strongly pushed Block #2 makes contact with strong-student D's hands). To facilitate comparison of the time variations of acceleration, velocity, and displacement, the t-axes are aligned. (Similar to the x, v, and a curves of the "fine motion" experiment in SDI Lab #0.2.) Use a solid line (———) labeled "Strong" for the strongly pushed Block #2. Use a dashed line (– – – –) labeled "Weak" for the weakly pushed Block #1. Use the standard color code for your lines: ***orange*** for acceleration, ***green*** for velocity, and ***blue*** for displacement. [HINT: Recall your F(t) curve on p. 7.]
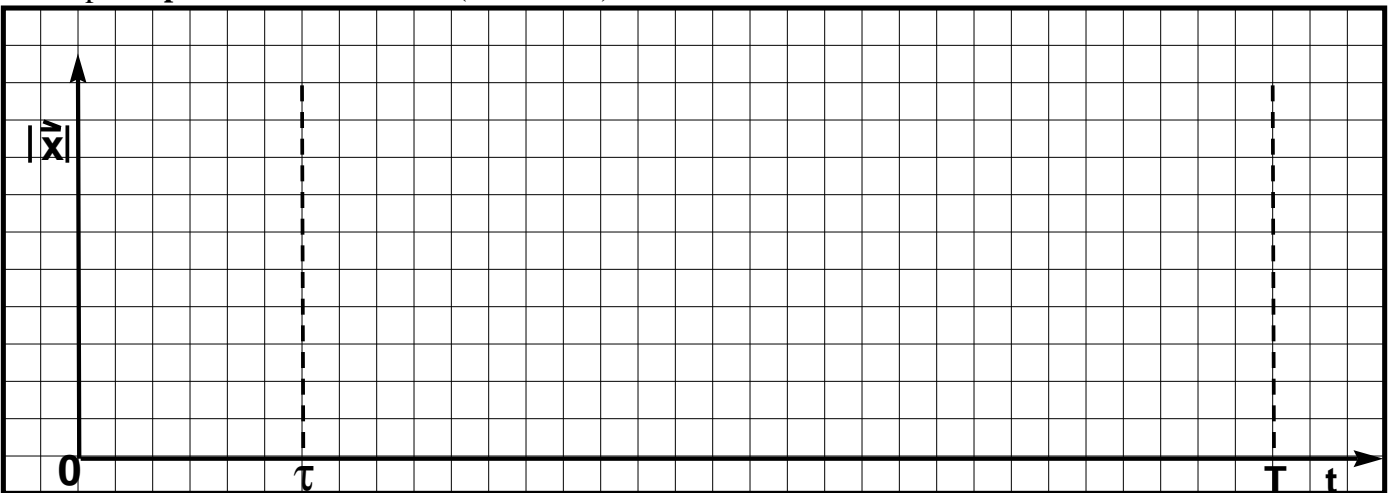
a. Graph **acceleration** a vs time t (orange curve) .
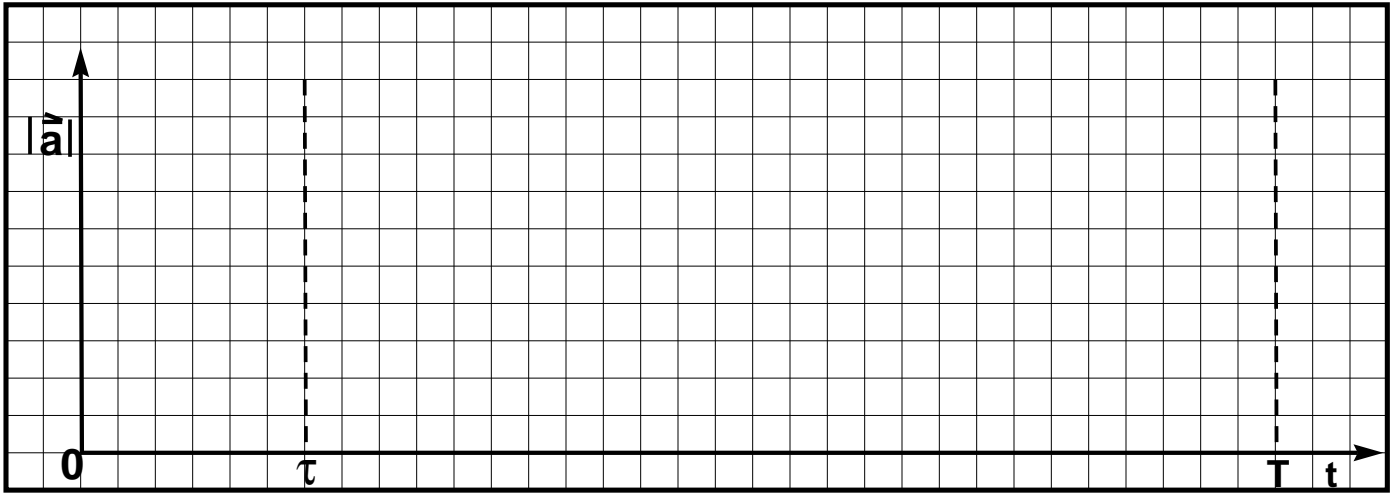
b. Graph **velocity** v vs. time t (green curve).

c. Graph **displacement** x vs time t (blue curve).

4. Considering your observations of the motion as depicted in the above snapshot sketches and the above graphs:

    a. Are the **accelerations** of the two blocks equal at any clock reading during the time interval T ? {Y, N, U, NOT} Is your answer in accord with your earlier prediction? {Y, N, U, NOT}

    b. Are the **velocities** of the two blocks equal at any clock reading during the time interval T ? {Y, N, U, NOT} Is your answer in accord with your earlier prediction? {Y, N, U, NOT}

    c. Are the **displacements** of the two blocks equal at any clock reading during the time interval T? {Y, N, U, NOT} Is your answer in accord with your earlier prediction? {Y, N, U, NOT}

    d. What is the shape of $v(0 \leq t \leq \tau)$ in Graph b? (This is a standard short-hand way of asking "What is the shape of the curve of speed v as a function of time t over the time interval from $t = 0$ to $t = \tau$ in Graph b?")

    e. How is the magnitude $v(0 \leq t \leq \tau)$ at any time t_p in Graph b related to $a(0 \leq t \leq t_p)$ of Graph a? {HINT: If you have completed a course in calculus recall the meaning of an *integral* in terms of the area under a curve.}

f. What is the shape of $x(0 \le t \le \tau)$ in Graph c?

g. How is the magnitude $x(0 \le t \le \tau)$ at any time t_p in Graph c related to $v(0 \le t \le t_p)$ of Graph b? [HINT: Same as in "e" above.]

h. What is the shape of $x(\tau \le t \le T)$ in Graph c?

i. Do the curves $x(0 \le t \le \tau)$ and $x(\tau \le t \le T)$ have a discontinuous change in their slopes at $t = \tau$? {Y, N, U, NOT}

j. How is the *slope* of $x(t)$ in Graph c related to the magnitude of v in Graph b? {HINT: If you have completed a course in calculus recall the meaning of a *derivative* in terms of the slope of the tangent at a point on a curve.}

k. How is the *slope* of $v(t)$ in Graph b related to the magnitude of a in Graph a? {HINT: Same as for "j" above.}

IV. VERTICAL MOTION OF ONE BALL

   A. Go to the central area of the lab where the ceiling is at its highest (about 3.6 m). Throw one of the rubber balls vertically upward so that it rises about 2 m to a point near the ceiling and then falls to the floor. The figure below shows the ball in 6 sequential positions after the ball has left contact with your hand. The top position is at the top of the ball's path. The upward and downward paths have been displaced for clarity. Show ALL the **force** vectors acting on the ball at these 6 positions. Draw **velocity** vectors if you think they exist. Draw **acceleration** vectors if you think they exist.

MOTION OF A BALL THROWN VERTICALLY INTO THE AIR
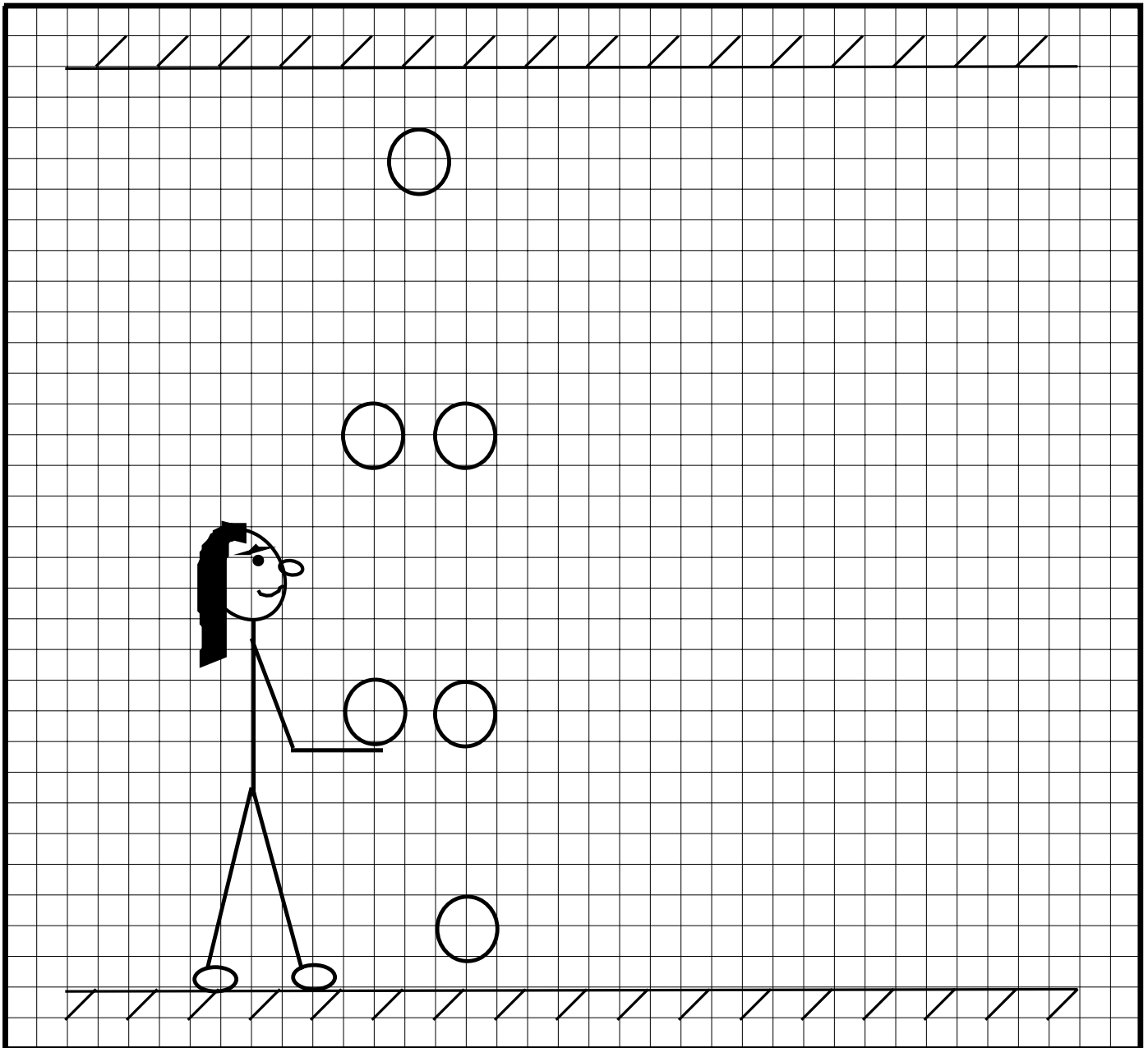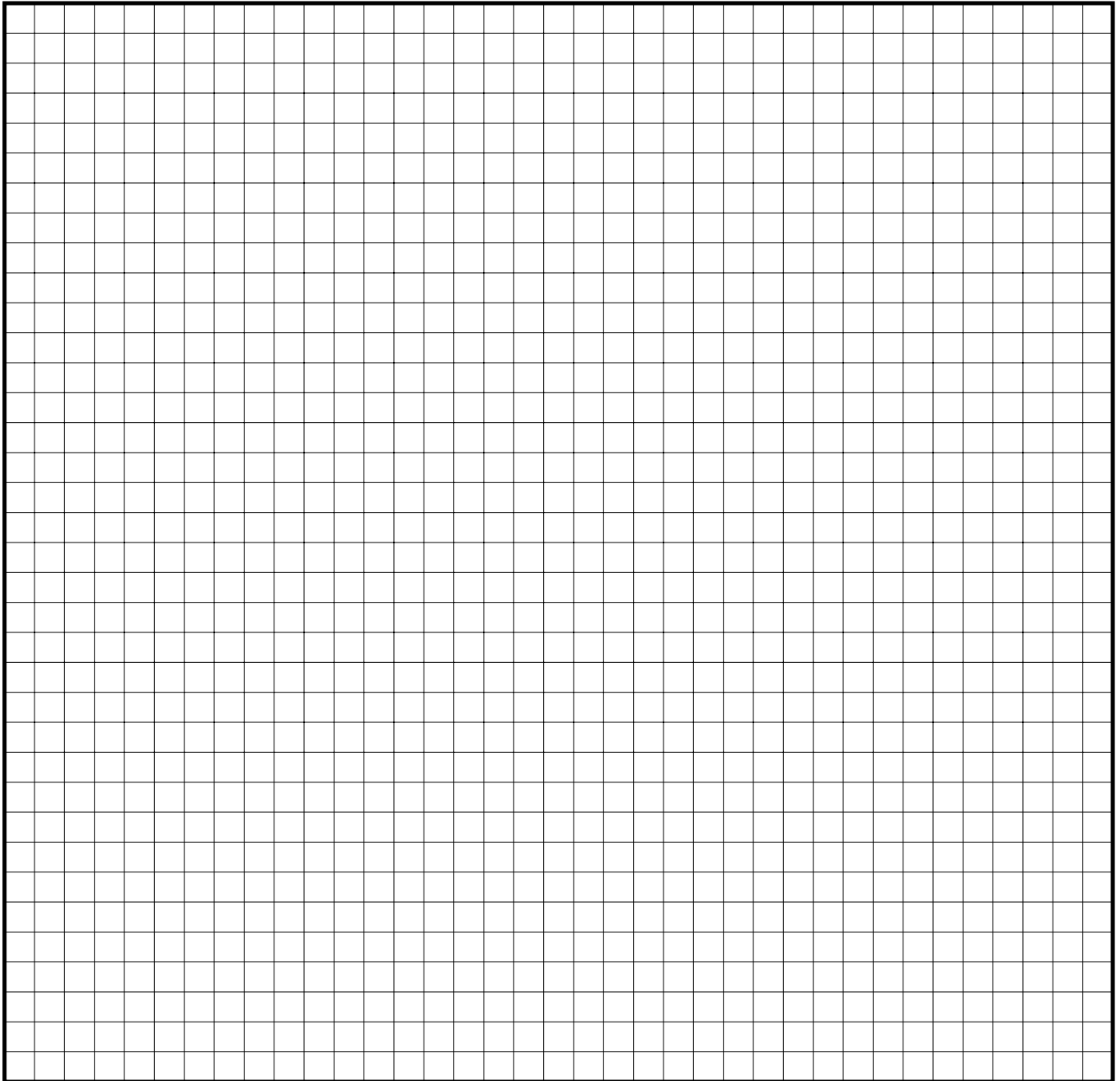

   1. Are your 6 sketches qualitatively consistent with Newton's second law,

$\vec{\mathbf{F}}_{\text{net on body}} = m_{\text{body}}\vec{\mathbf{a}}_{\text{body}}$? {Y, N, U, NOT} (Justify your answer on the right side of the figure.)

V. PROJECTILE MOTION OF ONE BALL

A. Throw a rubber ball across the room to your partner in a graceful arc. Watch the path of the ball thrown similarly between other partners from a position such that your line of sight is perpendicular to the plane of the ball's path. Sketch the path. Sketch the ball at 5 positions: (1) just after leaving the thrower's hand, (2) 1/2 of the way to the top of its path, (3) at the top of its path, (4) 1/2 of the way to the bottom of its path, (5) just before reaching the catcher's hands. In the space below show ALL the **force** vectors acting on the ball at these 5 positions. Draw horizontal, vertical, and resultant **velocity** vectors at each position. Draw **acceleration** vectors if you think they exist.

MOTION OF A BALL THROWN THROUGH THE AIR IN A GRACEFUL ARC

1. Are your 5 sketches qualitatively consistent with Newton's second law, $\vec{\mathbf{F}}_{\text{net on body}} = m_{\text{body}}\vec{\mathbf{a}}_{\text{body}}$? {Y, N, U, NOT}

VI. PROJECTILE MOTION OF SIX BALLS

A. Juggle six balls *of different masses* simultaneously in two hands, keeping all balls in the air except for very brief hand contacts. While juggling, sketch in the space below the positions of all six balls *at some instant of time when all balls are out of contact with your hands.* Show the **velocity** vectors of all six balls. (The particular velocities and positions of the balls will depend on your juggling technique but are irrelevant for this experiment, *as long as the ball velocities have widely different magnitudes and directions.*) Show ALL the **force** vectors acting upon the six balls. Show the **acceleration** vectors for all six balls. [NOTE: Did you sneak into this course without the prerequisite Juggling 107? If so, merely place 6 balls of different masses into a box and throw them simultaneously out of the box and into the air so that their velocities have widely different magnitudes and directions.]

VELOCITY, FORCE, AND ACCELERATION VECTORS OF SIX JUGGLED BALLS OF DIFFERENT MASSES AT AN INSTANT WHEN ALL OF THEM ARE IN THE AIR
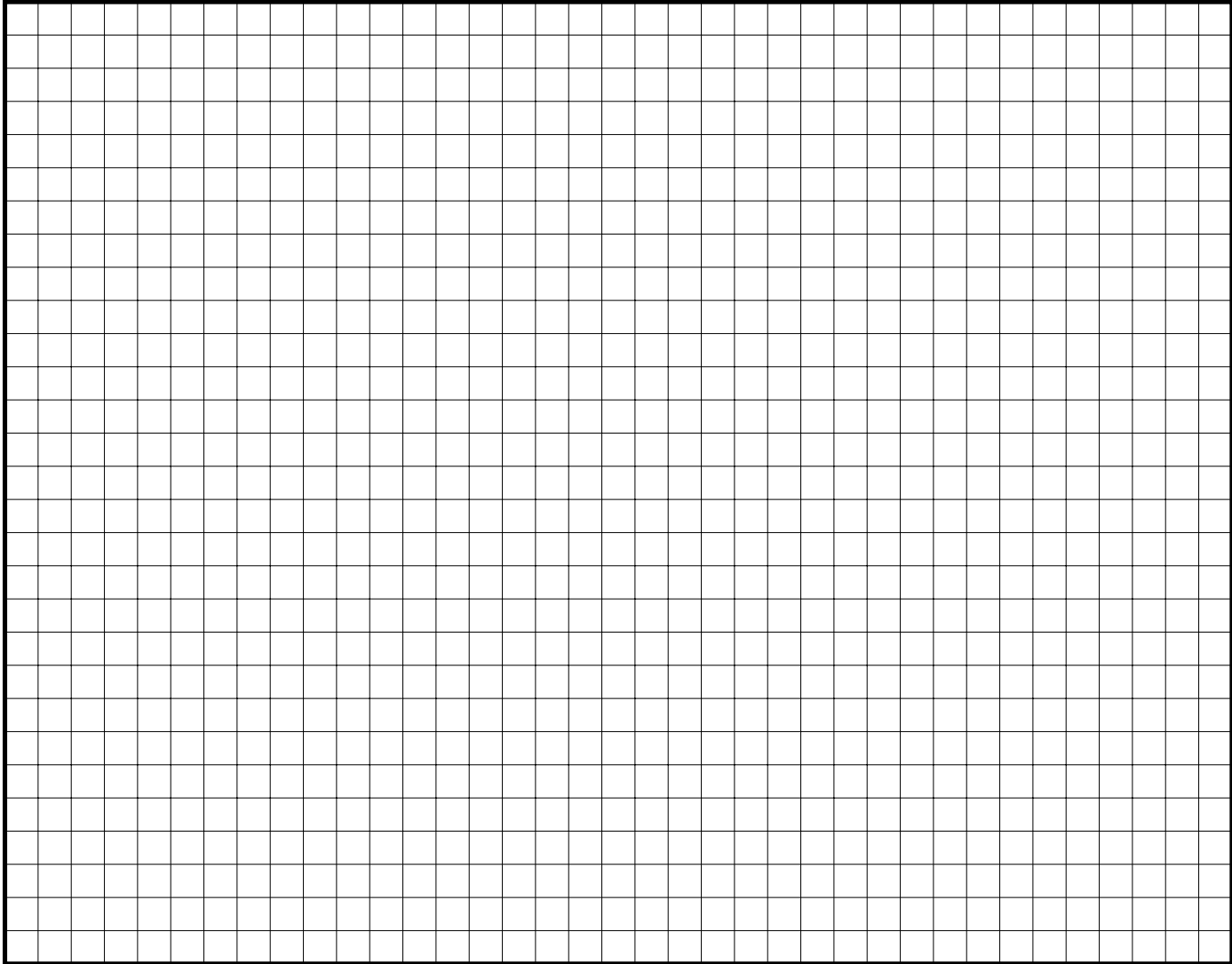
   1. Are your sketches qualitatively in accord with Newton's second law (N2), $\vec{F}_{\text{net on body}} = m_{\text{body}} \vec{a}_{\text{body}}$? {Y, N, U, NOT} (After answering this question you may stop juggling the six balls.)

VII. PROJECTILE MOTION - COMPUTER INVESTIGATION

Please complete the preceding Sections V and VI on projectile motion and discuss them with an instructor before starting this section.

Ask your instructor to introduce you to the Force-Motion-Vector Animation (FMVA) *Trajectory.*[†] Play around with the program until you understand the various controls and readouts.

Note that the range of selectable values for the launch speed v_o(0 - 10 m/s), the mass of the ball m (0.03 - 0.2 kg), launch angle θ (0° - 180°), and launch height H (0 - 3m), span the actual values as experienced in the lab. Thus simulations of the motions previously investigated in Sec. V ("Vertical Toss...") and Sec. VI ("Projectile Motion....") are possible, except that the motion as seen on the computer screen is slower than in the lab. (Note, however, that the time readout on the computer screen is the elapsed time interval Δt for the actual lab motion, not the much larger time interval ΔT as observed by someone watching the slow-motion animation.) The magnitude of the acceleration $\vec{a}$ due to the earth's gravitational force $\vec{W}$_{on ball by Earth} is normally set at g = 9.8 m/s^2, but can be changed over the range $0.1 \le g \le 20$ m/s^2 if you wish to simulate, say, the motion of the ball on the moon (g = 1.7 m/s^2) or on Jupiter (g = 19 m/s^2).

A. "VERIFY" *TRAJECTORY* (Before you start select ***all*** the options except *Track Ball*. Select *Background Image* if you wish to see a sunset. Note that the grid lines are 1.0 m apart. Select a Zoom setting of 200. Simulate the experiment done in Sec. V, Projectile Motion of One Ball, g = 9.8 m/s^2, mass of the ball m = 0.10 kg, launch angle θ = 60°, and launch height H = 0.00 m. Set the launch speed v_{ox} such that the maximum height of the trajectory h = 2.00 m. For future reference, record v_{ox} = _____ m/s and range R = _____m.   Set the time t so as to place the ball at a height of about 1.0 m.

    1. PREDICTION - Increasing the Mass of the Ball

       If you were to double the mass m of the ball to m = 0.20 kg, leaving all other parameters unchanged, would the:

       a. Vertical force $\vec{W}$_{on ball by Earth} decrease, remain the same, increase, or none of these? (Encircle one and justify your answer.)

       b. *Direction* of the acceleration $\vec{a}$ of the ball remain the same or change? (Encircle one and justify your answer.) (Encircle one and justify your answer.)

       c. *Magnitude* of the acceleration $\vec{a}$ of the ball decrease, remain the same, increase, or none of these? (Encircle one and justify your answer.) (Encircle one and justify your answer.)

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d. Black curve representing the trajectory of the ball change such that the height and range both increase, the height and range both decrease, the height stays the same but the range decreases, the range stays the same but the height decreases, none of these. (Encircle one and justify your answer.)

1'. COMPUTER TEST - Increasing the Mass of the Ball.
       Perform the operation in "1" above. Encircle the results in red in "1a,b,c,d" above, then compare your prediction with the computer results in 1a',b',c',d' below.
   a'.   Does your prediction agree with the computer result? {Y, N, U, NOT} If not "Y" either show that the computer is wrong or else justify the computer result.

   b'. Does your prediction agree with the computer result? {Y, N, U, NOT} If not "Y" either show that the computer is wrong or else justify the computer result.

   c'.   Does your prediction agree with the computer result? {Y, N, U, NOT} If not "Y" either show that the computer is wrong or else justify the computer result.

   d'. Does your prediction agree with the computer result? {Y, N, U, NOT} If not "Y" either show that the computer is wrong or else justify the computer result.

4. Pull down the Action Menu and select *Throw Ball.* Indicate the computer's reading of the time interval T =_____sec for the ball to traverse its trajectory.

5. Does the ball behave more or less as observed in Sec. V, Projectile Motion of One Ball? Use the time slider to set the ball at about the same positions as in your diagrams of Sec. V. Select the *Track Ball* option to keep all the vectors in view at all points on the trajectory. Do the vectors shown by the computer agree qualitatively with those in your diagrams.{Y, N, U, NOT} If not "Y" either show that the computer is wrong or else justify the computer result.

6. Deselect *Track Ball,* press *Throw Ball* and watch the animation several times. Then select the *Track Ball* option (since this will allow you to more easily concentrate on the time dependence of the vectors). Watch the animation several more times. The animation allows you to observe the continuous *time dependence* of kinematic parameters such as position; and the velocity, acceleration, and force vectors. This contrasts with your snapshot sketches of Sec. V which show these parameters only at *instants* in time.

   a. Do the velocity, acceleration, and force vectors shown for the ball using the "Track Ball" option, appear to be those that would be measured by an observer in the Earth reference frame? {Y, N, U, NOT}

   b. Qualitatively describe the time dependence of the force $\vec{W}_{\text{on ball by Earth}}$. Is this consistent with Newton's Universal Law of Gravitation?{Y, N, U, NOT}

c. Qualitatively describe the time dependence of the acceleration $\vec{a}$, in both the vertical and horizontal directions. Is this consistent with your answer to "b" and Newton's second law, $\vec{F}_{net\ on\ body} = m_{body}\vec{a}_{body}$? {Y, N, U, NOT}

d. Qualitatively describe the time dependence of the *horizontal* velocity $\vec{v}_h$. Is this consistent with your answer to "c" above? {Y, N, U, NOT}

e. Qualitatively describe the time dependence of the *vertical* velocity $\vec{v}_v$. Is this consistent with your answer to "c" above? {Y, N, U, NOT}

f. In considering "e" above, does the time dependence of the vertical velocity $\vec{v}_v$ change as the ball passes through the top of its path? {Y, N, U, NOT}

7. Considering A1 - A7 above, what level of confidence do you have that *Trajectory* gives a true representation of the real world of Newtonian mechanics? Encircle one very high, high, medium, low, very low. Explain your choice.

B. INVESTIGATE THE PROJECTILE MOTION OF ONE BALL USING *TRAJECTORY*
     Investigate various aspects of the ball's motion as shown in *Trajectory* so as to answer the questions below.
     1. With the same options and settings as in "A" above, repeat A-4 above by pulling down the Action Menu and selecting *Throw Ball*.   Verify that the launch speed v_{ox} and the time for the motion T are as recorded in part A. Record all the settings here for reference:

          launch speed v_{ox} = _____m/s,
          launch angle $\theta = 60°$,
          acceleration due to gravity g = 9.8 m/s,
          launch height H = 0.00 m,
          mass of the ball= 0.1 kg,
          h (height of path) = 2.00m,
          time to traverse path T = _____s,
          range of trajectory R = _____m.

     2. PREDICTION - Changing Launch Angle & Speed with Maximum Path Height Constant
     If you were to decrease the launch angle θ to 45°, and increase the launch speed so as to keep the maximum height h of the path constant at 2.00m, would

     a. the time T to traverse the path decrease, remain the same, increase, or none of these?
        (Encircle one and justify your answer.)

     b. the range R of the path decrease, remain the same, increase, or none of these?
        (Encircle one and justify your answer.)

     2'. COMPUTER TEST - Changing Launch Angle & Speed with Maximum Path Height Constant
          Perform the operation in "2" above. (You may have to change the Zoom setting to keep the entire trajectory in view.) Encircle the results in red in "2a,b" above, then compare your prediction with the computer results in 2a',b' below.
     a'.   Does your prediction agree with the computer result? {Y, N, U, NOT} If not "Y" either show that the computer is wrong or else justify the computer result.

     b'. Does your prediction agree with the computer result? {Y, N, U, NOT} If not "Y" either show that the computer is wrong or else justify the computer result.

3. Maximizing the Range of a Projectile

    a. Set the launch speed at its maximum of $v_o = 10$ m/s, the launch height $H = 0$, and the Zoom at 75. Vary the launch angle θ so as to find the angle which *maximizes* the "range" R (the horizontal distance that the ball travels in the air). This is the θ which maximizes R when the ball takes off and lands at ground level (as can occur when driving a golf ball or kicking a soccer ball). What is this angle? θ (H = 0m) = _____.

    b. With the same launch speed $v_o = 10$ m/s and Zoom = 75 as above, adjust the launch height to $H = 2.0$m. Again vary the launch angle θ so as to find the angle which *maximizes* the range R. This is the θ which maximizes R for the shot put if the shot takes off at H = 2.0 m (close to that for champion shotputters) and lands at ground level. What is this angle? θ (H = 2.0m) = _____. Do you think that these results are of any significance for champion shot putters? {Y, N, U, NOT}

VIII. MOTION OF A PENDULUM BOB

    A. SWINGING PENDULUM BOB - YOUR PRE-EXPERIMENT IDEAS ON FORCE AND MOTION VECTORS

    Set the rubber-ball pendulum bob near your table swinging. Observe its poetic to-and-fro motion from a position such that your line of sight is perpendicular to pendulum's plane of motion. In Fig. 2 below draw ALL the **force**, **velocity**, and **acceleration** vectors acting on the bob at the 5 positions shown using red, green, and orange arrows, in accord with your current ideas.

    HINT: It helps to consider the radial and tangential components of the force and acceleration vectors (see Giancoli, p. 115, 116).
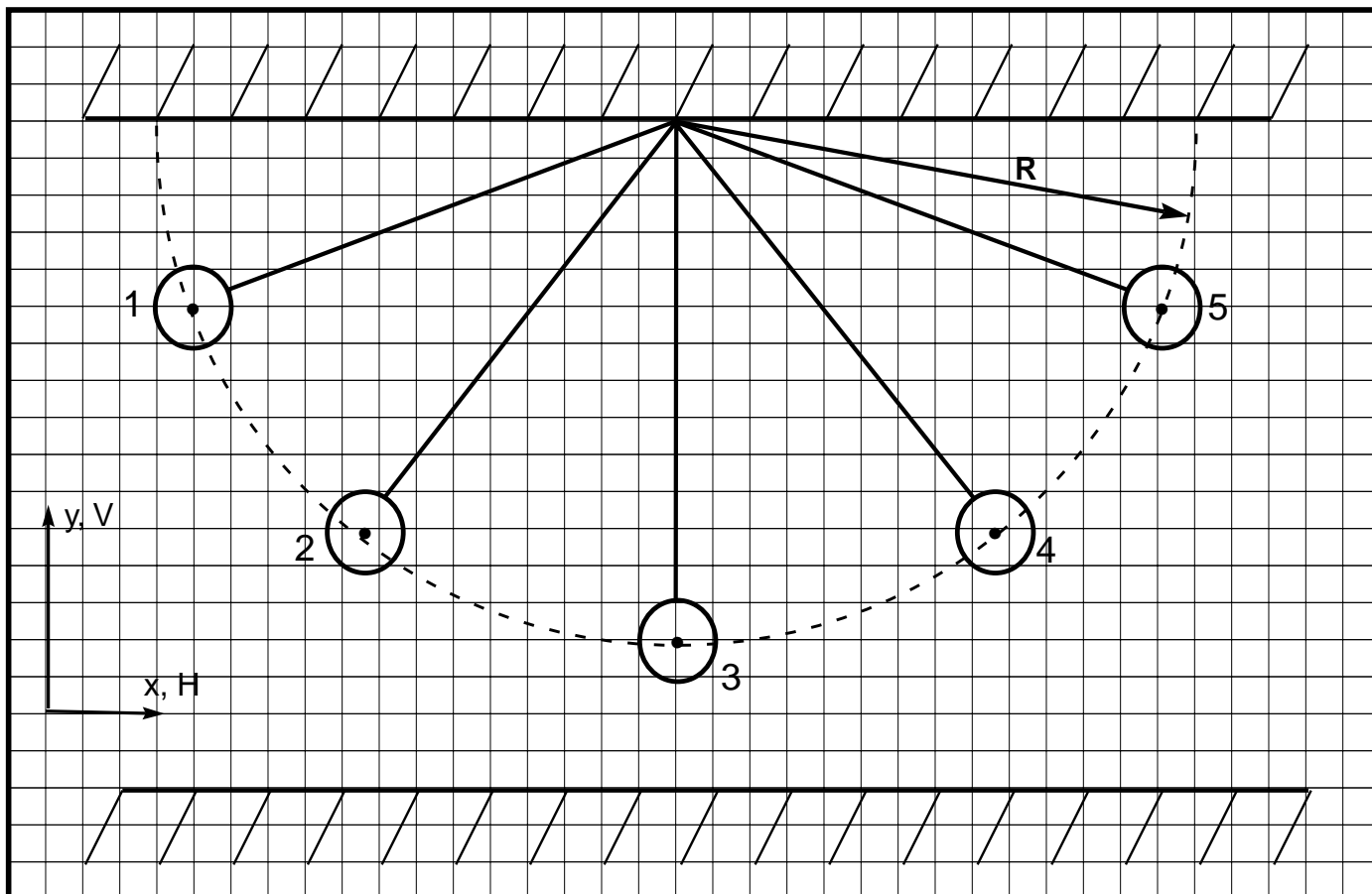
Fig. 2. Motion of a pendulum bob swinging from left to right. Positions #1 and #5 are at the highest points of the path. Show ALL the force, velocity, and acceleration vectors for the bob at the 5 positions shown, in accord with your pre-experiment ideas.

B. THOUGHT EXPERIMENT

In considering the string tension T acting on the bob, it's helpful to first observe the extension of a small spring scale (tied so as to replace a small segment of the string) as the bob (a) is supported by your hand so that T = 0, (b) hangs stationary so that T is just equal to the weight of the bob, thereby yielding some scale reading "w." It's important to realize that *the spring extension is directly proportional to the tension T.*   **YOUR OBSERVATIONS CAN BE MADE ON A RELATIVELY LONG PENDULUM (WITH A SPRING-SCALE INSERT IN THE STRING) WHICH HANGS FROM THE CEILING AT THE CENTER OF THE LAB**. Your instructor will introduce you to this "giant pendulum."

Suppose you were to set the pendulum bob swinging back and forth. Consider the spring extension "**l**" that would be observed at the **l**ow point of the swing, and the spring extensions "**h**" that would be observed at the **h**igh points of the swing. Indicate how your *predicted* extensions compare with the extension "w" due to the weight of the stationary bob:

> *Predicted* Low-Point Extension (encircle one) :   l > w,   l = w,   l < w;

> *Predicted* High-Point Extension (encircle one):   h > w,   h = w,   h < w.

Can you explain your predictions? {Y, N, U, NOT}   [HINT: Think of similar situations in your experience and/or apply your Newtonian knowledge and the **WIESE** (pronounced "wise") strategy: **W**hat's happening?, **I**dealized model, **E**quations, **S**ubstitute, **E**valuate.

C. REAL EXPERIMENT: Perform the experiment. Start the pendulum off in such a way that the radial oscillation of the bob is minimized (you may need some help from your instructor.)   Indicate how the *observed* extensions compare with the extension "w" due to the weight of the stationary bob:

        Observed Low-Point Extension (encircle one) : $l > w$, $l = w$, $l < w$;

        Observed High-Point Extension (encircle one): $h > w$, $h = w$, $h < w$.

Were your predictions for the low-point extension "l" correct? {Y, N, U, NOT}

Were your predictions for the high-point extension "h" correct? {Y, N, U, NOT}

D. SWINGING PENDULUM BOB - YOUR POST-EXPERIMENT IDEAS ON FORCE AND MOTION VECTORS

In Fig. 3 draw ALL the force, velocity, and acceleration vectors acting on the bob at the 5 positions shown in accord with your post-experiment ideas. In thinking about the acceleration vectors, first consider position #3 at the bottom of the path and utilize your observations in "C" above. Then consider positions #1 and #5 at the top of the path. For the latter points, it helps to consider a small time increment Δt near the instant at which the bob is at the top of its path and apply the *definition* of acceleration:

$$\vec{\mathbf{a}} \equiv \lim_{\Delta t \to 0} [\Delta \vec{\mathbf{v}} / \Delta t] = \lim_{\Delta t \to 0} [(\vec{\mathbf{v}}_f - \vec{\mathbf{v}}_i) / \Delta t] \ ....(1)$$

where $\Delta \vec{\mathbf{v}} \equiv$ change in velocity over the time increment Δt

$\vec{\mathbf{v}}_f \equiv$ velocity at *end* of time increment Δt

$\vec{\mathbf{v}}_i \equiv$ velocity at *start* of time increment Δt

After drawing in the acceleration vectors with *solid* orange arrows at positions #1, 3, 5, you should be able to approximate the accelerations at positions #2, 4 by *interpolation* (i.e., by estimating values between two known values).
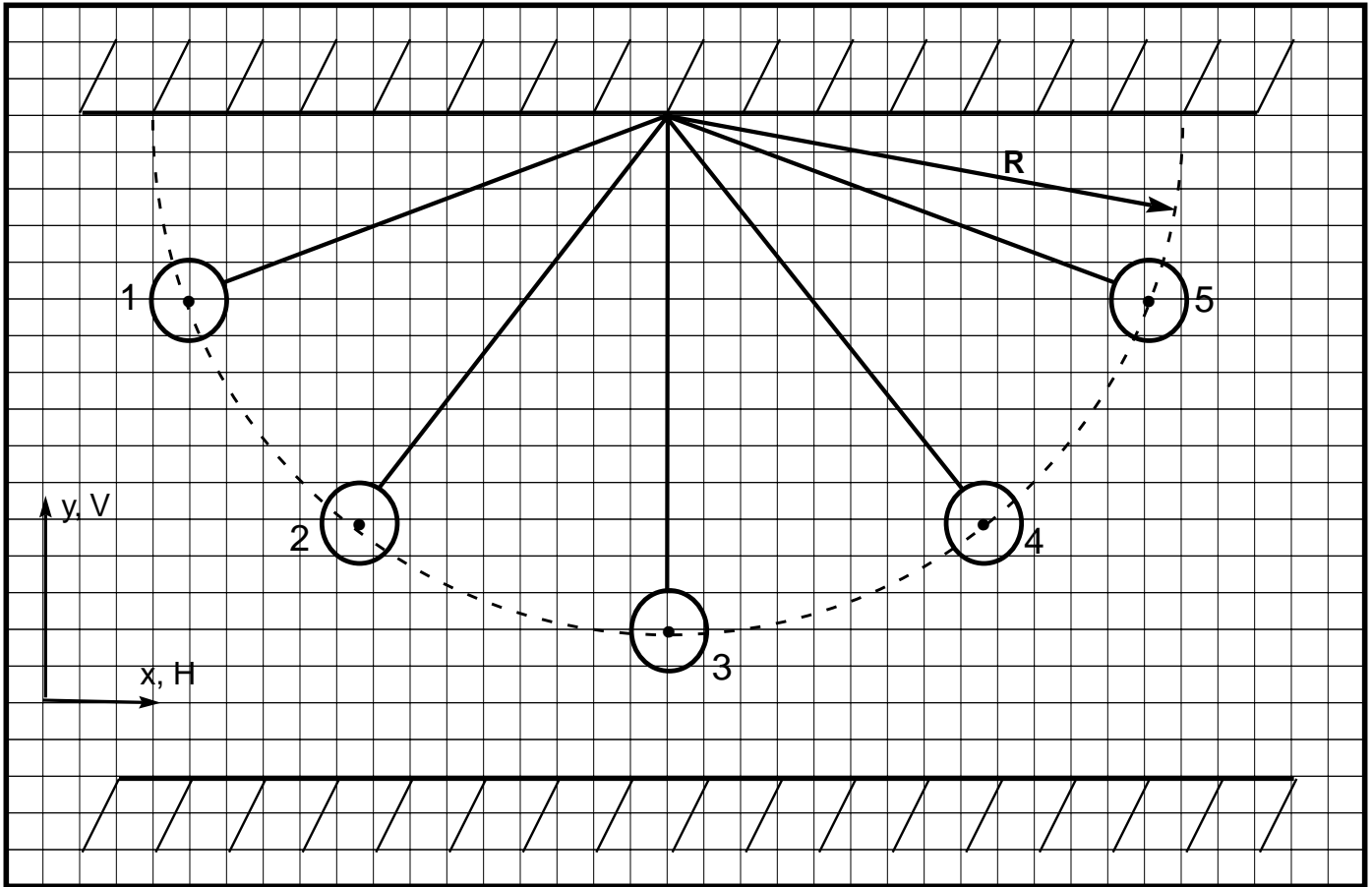
Fig. 3. Motion of a pendulum bob swinging from left to right. Positions #1 and #5 are at the highest points of the path. Show ALL the force, velocity, and acceleration vectors for the bob at the 5 positions shown in accord with your post-experiment ideas.

1. Are your sketches in Fig. 3 in qualitative accord with Newton's second law (N2),

$\vec{\mathbf{F}}_{\text{net on body}} = m_{\text{body}} \vec{\mathbf{a}}_{\text{body}}$? {Y, N, U, NOT}

E. RELEASED PENDULUM BOB

   1. Prediction

Suppose that at position "5" (the top of the path), the pendulum bob suddenly ceased being constrained by the string. In Fig. 4, draw your *prediction* of the path of the pendulum bob after its release.
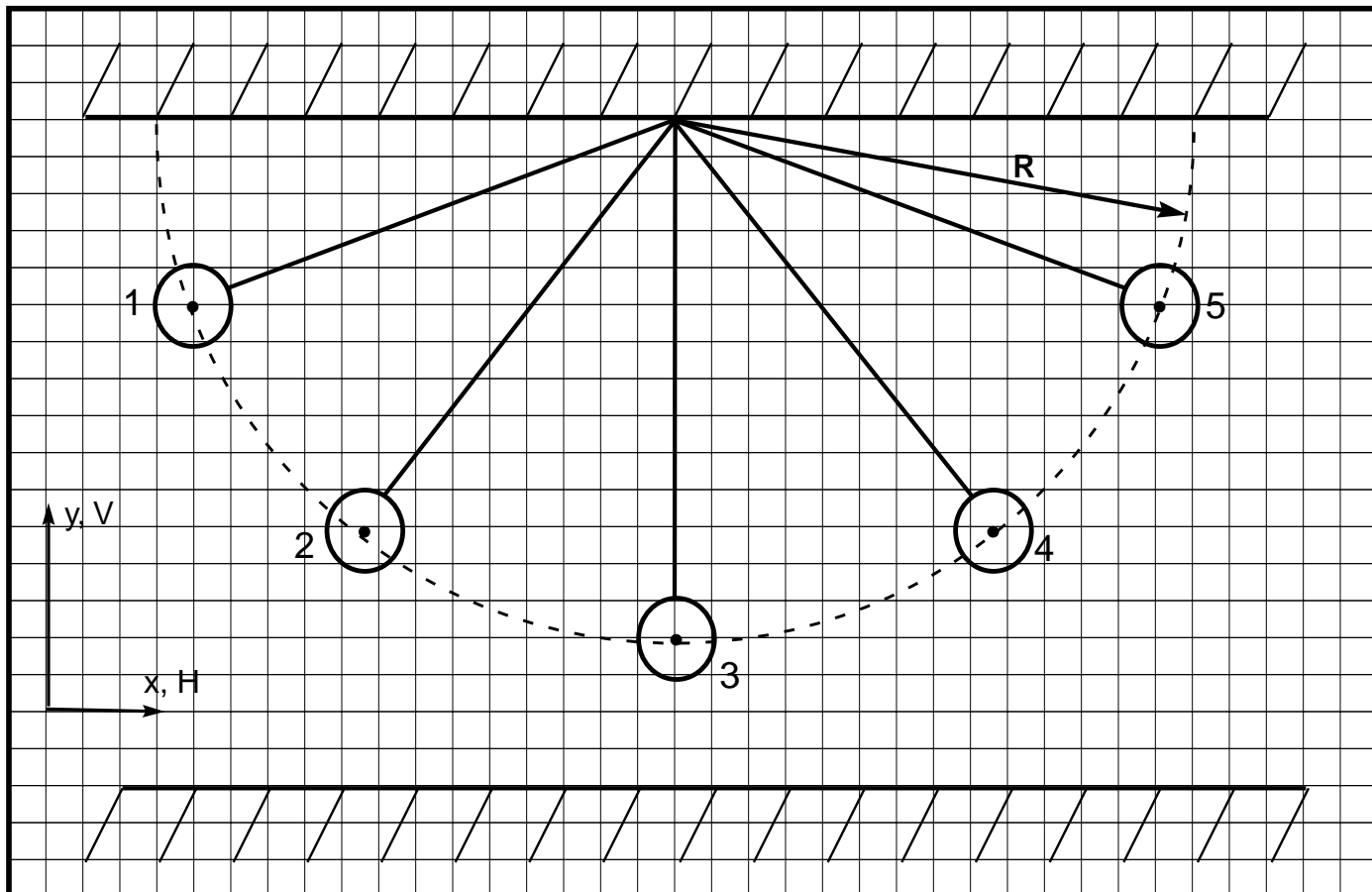

Fig. 4. A pendulum bob is released at position #5. Show your *prediction* of the path after release.

   2. Can you think of a way to actually perform this experiment?   (Note that you must change only one variable at a time — the pendulum must swing exactly as on shown on the previous page, except for the release at position 5. {Y, N, U, NOT}

   3. If your answer to "2" is "Yes," then perform the experiment. In Fig. 5, draw your *observation* of the path of the pendulum bob after its release.

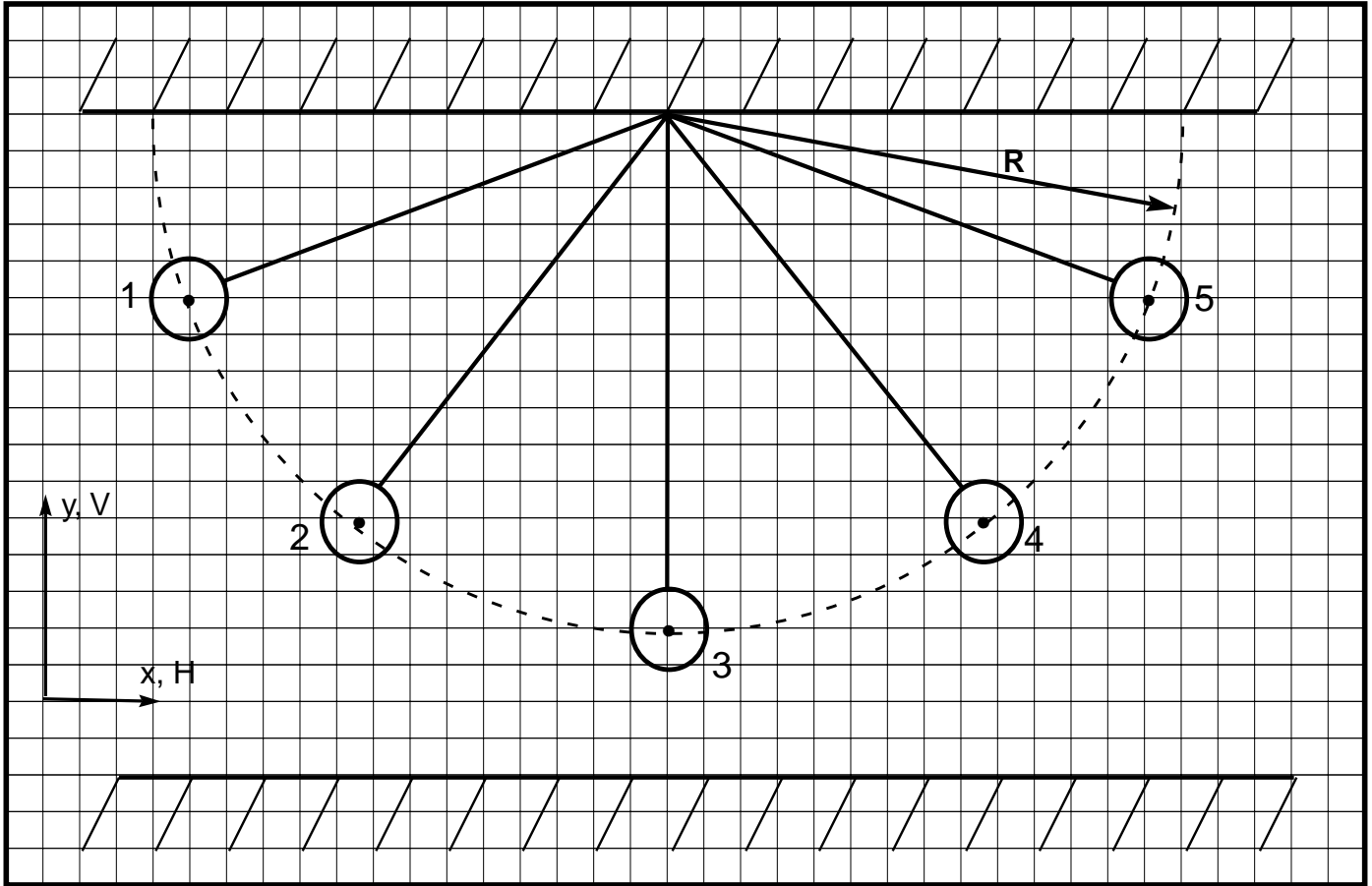   If your answer is "No," then confer with an instructor.

Fig. 5. A pendulum bob is released at position #5. Show your *observation* of the path after release.

4. Does your prediction of the path shown in Fig. 4 agree with your observations shown in Fig. 5? {Y, N, U, NOT}

5. Is the observed path of the released pendulum ball in agreement with Newton's second law (N2), $\vec{F}_{\text{net on body}} = m_{\text{body}}\vec{a}_{\text{body}}$? {Y, N, U, NOT}

IX. MOTION OF A PENDULUM BOB - COMPUTER INVESTIGATION

Please complete the preceding Section VIII "Motion of a Pendulum Bob" and discuss it with an instructor before starting this section.

Ask your instructor to introduce you to the Force-Motion-Vector Animation (FMVA) *Pendulum.*[†]
Play around with the program until you understand the various controls and readouts.

A. Pull down the Options Menu and select: *Trajectory*, *Velocity*, A*cceleration components*, *String Tension*, and *Weight*. Use the sliders to set the length L = 2.00m, initial angle θ = 70°, and mass of the ball m = 0.10 kg so they are similar to experiment of Sec. VIII-D. Pull down the Action Menu and select *Swing Ball*. Watch the animation. Now use the time slider to successively set the bob at the Fig. 3 positions #3, 4, and 5.

Do the force, velocity, and acceleration vectors displayed in *Pendulum* agree qualitatively with your diagrams in Fig. 3? {Y, N, U, NOT} If your answer to "A" is "No" please list the differences and show either that the vectors of Fig. 3 are correct or that those shown in *Pendulum* are correct on the basis of Newton's Second Law $\vec{F}_{\text{net on body}} = m_{\text{body}}\vec{a}_{\text{body}}$ and/or the definitions:

$$\vec{v} \equiv \lim_{\Delta t \to 0} [\Delta\vec{r} / \Delta t] = \lim_{\Delta t \to 0} [(\vec{r}_f - \vec{r}_i) / \Delta t]$$

$$\vec{a} \equiv \lim_{\Delta t \to 0} [\Delta\vec{v} / \Delta t] = \lim_{\Delta t \to 0} [(\vec{v}_f - \vec{v}_i) / \Delta t]$$

B. Pull down the Action Menu, select "Swing Ball," and watch the animation.

1. Does the velocity $\vec{v}$ change continuously as the bob moves through it's high point?
{Y, N, U, NOT} Is this consistent with the acceleration $\vec{a}$ shown at the high point?
{Y, N, U, NOT}

2. Does the velocity $\vec{v}$ change continuously as the bob moves through it's low point?
{Y, N, U, NOT} Is this consistent with the acceleration $\vec{a}$ shown at the low point? {Y, N, U, NOT}

[†] Written by Randall Bird for *Project Socrates.* Bird's animations, running only on Power Macs, are available on 3.5-in HD disks by request to R.R. Hake. Similar animations running on a variety of platforms are commercially available as "Interactive Physics" from Knowledge Revolution.

C. Pull down the Options Menu and select: *Trajectory*, *Velocity*, A*cceleration*, *Net Force.* Select *Swing Ball*, in the Action Menu and watch the animation. Are the $\vec{F}_{net}$ and $\vec{a}$ vectors in accord with Newton's Second Law $\vec{F}_{net\ on\ body} = m_{body}\vec{a}_{body}$? {Y, N, U, NOT}

X. MOTION OF FALLING BODIES

A. STEEL BALL vs PAPER COFFEE FILTER*

Hold a steel ball and a paper coffee filter (so that it appears as an upright-bowl) at about eye level and at about equal distances from the floor. Drop them simultaneously (use a rocket-launching-type countdown). In the space below, sketch the paper and the steel ball at 3 instants of time (clock readings): (1) at the instant (call it t = 0) that the ball/paper loose contact with your hand, (2) when the steel ball is midway to the floor, (3) just before the steel ball hits the floor. Show all the **force** vectors acting on both the steel ball and the paper. Show the **velocity** and **acceleration** vectors for both the steel ball and the paper if you think they exist.
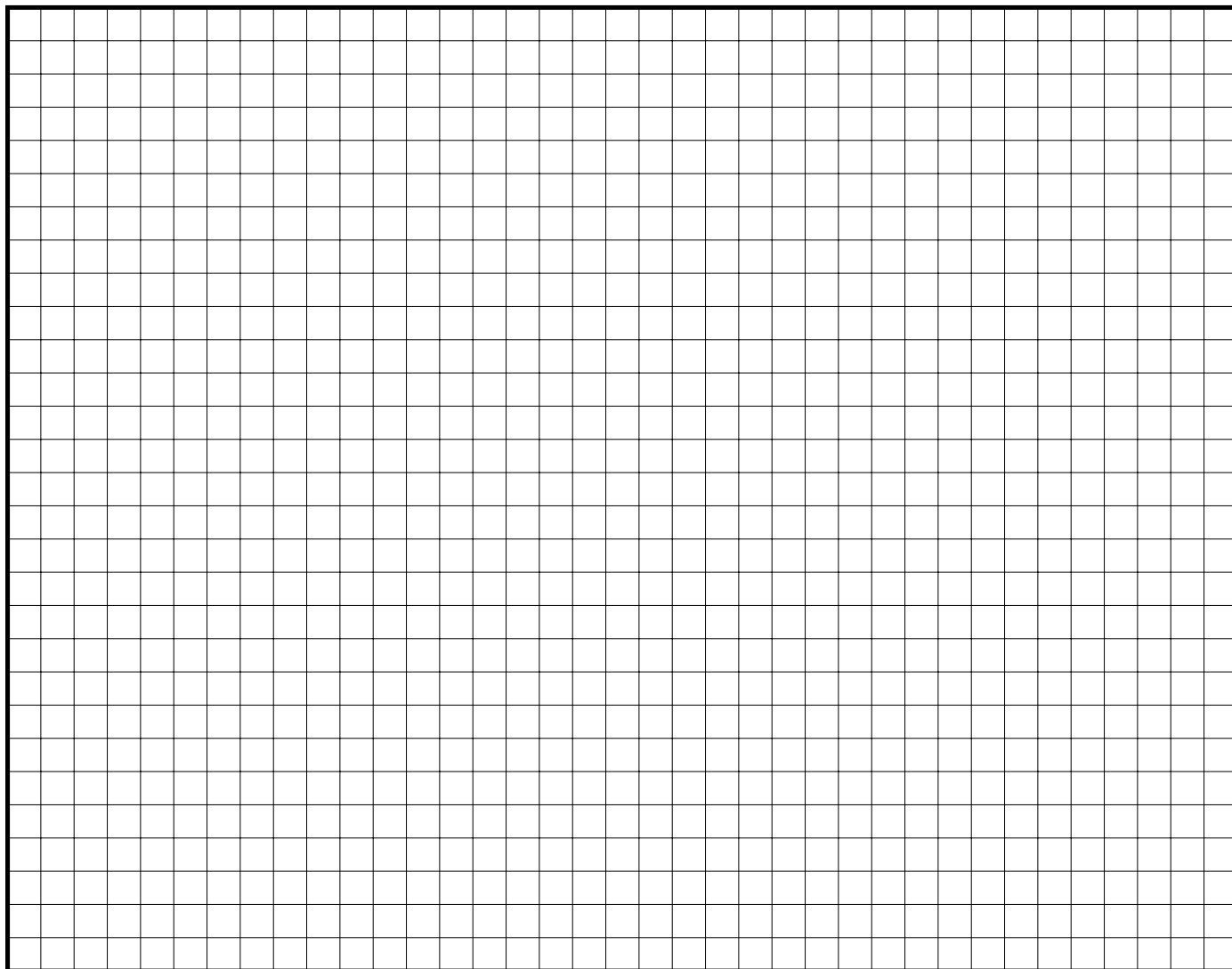
FALL OF A STEEL BALL AND A PAPER COFFEE FILTER

1. Are your sketches of the *motion of the steel ball* in qualitative accord with Newton's second law (N2), $\vec{F}_{\text{net on body}} = m_{\text{body}}\vec{a}_{\text{body}}$? {Y, N, U, NOT}

2. Are your sketches of the *motion of the paper coffee filter* in qualitative accord with Newton's second law (N2), $\vec{F}_{\text{net on body}} = m_{\text{body}}\vec{a}_{\text{body}}$? {Y, N, U, NOT} [HINT: Is air resistance important?]

3. Do your qualitative observations of the speeds of the falling steel ball and the falling paper filter:

    a. tend to support Aristotle's contention that heavier bodies fall faster than light bodies?
    {Y, N, U, NOT}

    b. prove Aristotle's contention? {Y, N, U, NOT}

    c. disprove Aristotle's contention? {Y, N, U, NOT}

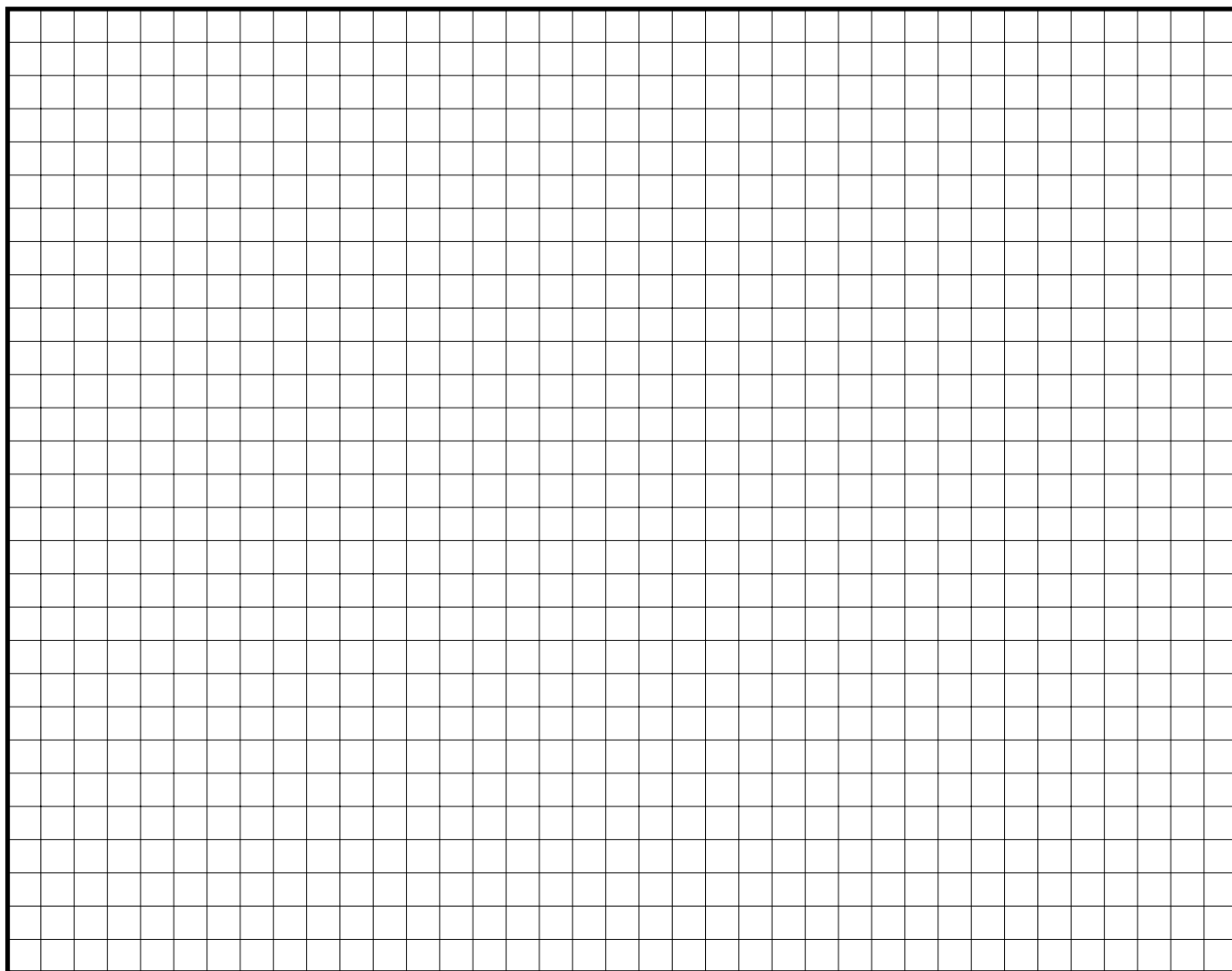   d. tend to support Newton's second law? {Y, N, U, NOT}

    e. prove Newton's second law? {Y, N, U, NOT}

    f. disprove Newton's second law? {Y, N, U, NOT}

4. Is the above experiment *in error*? {Y, N, U, NOT}

B. STEEL BALL vs PAPER COFFEE FILTER CRUMPLED INTO A BALL

Hold a steel ball and the same paper filter as in "A" above (except crumple the filter into a ball). Repeat the entire experiment just as in "A." In the space below, repeat the sketches called for in "A." Show ALL the **force** vectors acting on both the steel ball and the crumpled paper at the 3 positions. Show **velocity** and **acceleration** vectors on both the steel ball and crumpled paper if you think they exist.

FALL OF A STEEL BALL AND A PAPER COFFEE FILTER CRUMPLED INTO A BALL

1. Are your sketches in qualitative accord with Newton's second law (N2), $\vec{F}_{\text{net on body}} = m_{\text{body}}\vec{a}_{\text{body}}$? {Y, N, U, NOT}

2. Do your qualitative observations of the speeds of the steel ball and the crumpled paper:

    a. tend to support Aristotle's contention that heavier bodies fall faster than light bodies? {Y, N, U, NOT}

    b. prove Aristotle's contention? {Y, N, U, NOT}

    c. disprove Aristotle's contention? {Y, N, U, NOT}

    d. tend to support Newton's second law? {Y, N, U, NOT}

    e. prove Newton's second law? {Y, N, U, NOT}

    f. disprove Newton's second law? {Y, N, U, NOT}

3. Is the above experiment in error? {Y, N, U, NOT}

C. *DEMONSTRATING* FREE FALL TO AN ARISTOTELIAN

In the excellent *Mechanical Universe* tape *The Law of Falling Bodies*,***** lecturer David Goodstein of Cal Tech (that self-proclaimed Wimbledon, La Scala, and Monte Carlo of physics education) emphasizes that equal-acceleration free fall of all bodies near the surface of the earth is counter-intuitive and not commonly observed because experiments must be carried out in vacuum.

In *Dialogues Concerning Two New Sciences* (New York, Dover, 1952, originally published about 1638), Galileo of the Univ. of Pisa and later Padua (the Cal Tech's of their day) presents a somewhat different perspective on the same subject in the form of a conversation between Simplico (an Aristotelian) and Salviati (a Galilean):

> *Simplico*: Your discussion[†] is really admirable; yet I do not find it easy to believe a bird-shot falls as swiftly as a cannon ball.
>
> *Salviati*: Why not say a grain of sand as rapidly as a grindstone? But, Simplico, I trust you will not follow the example of many others who divert the discussion from its main intent and fasten upon some statement of mine that lacks a hairsbreadth of the truth, and under this hair hide the fault of another which is as big as a ship's cable. Aristotle says that "an iron ball of one hundred pounds falling from a height of one hundred cubits reaches the ground before a one-pound ball has has fallen a single cubit." I say that they arrive at the same time. You find, on making the experiment, that the larger outstrips the smaller by two fingerbreadths.... Now you would not hide behind these two fingers the 99 cubits of Aristotle, nor would you mention my small error and at same time pass over in silence his very large one.
>
> _____
>
> †The discussion concerned Galileo's ingenious thought experiment involving the fall of a light object and a heavy object tied together, as depicted in the *Mechanical Universe* tape *The Law of Falling Bodies*. For a good presentation see G. Holton and S.E. Brush, *Introduction to Concepts and Theories in Physical Science* (Princeton Univ. Press, 2nd ed. 1985) p. 83-85.

Suppose you were to demonstrate free fall by simultaneously dropping a heavy steel ball and a light crumpled paper filter from the same height above the floor as in part B above. Your keen-eyed Aristotelian friend notices that the steel ball is two fingerbreadths ahead of the paper just before the steel ball hits the floor. S(he) exclaims:

"**Hey, Aristotle had it right, heavy bodies *do* fall faster than light bodies!**"
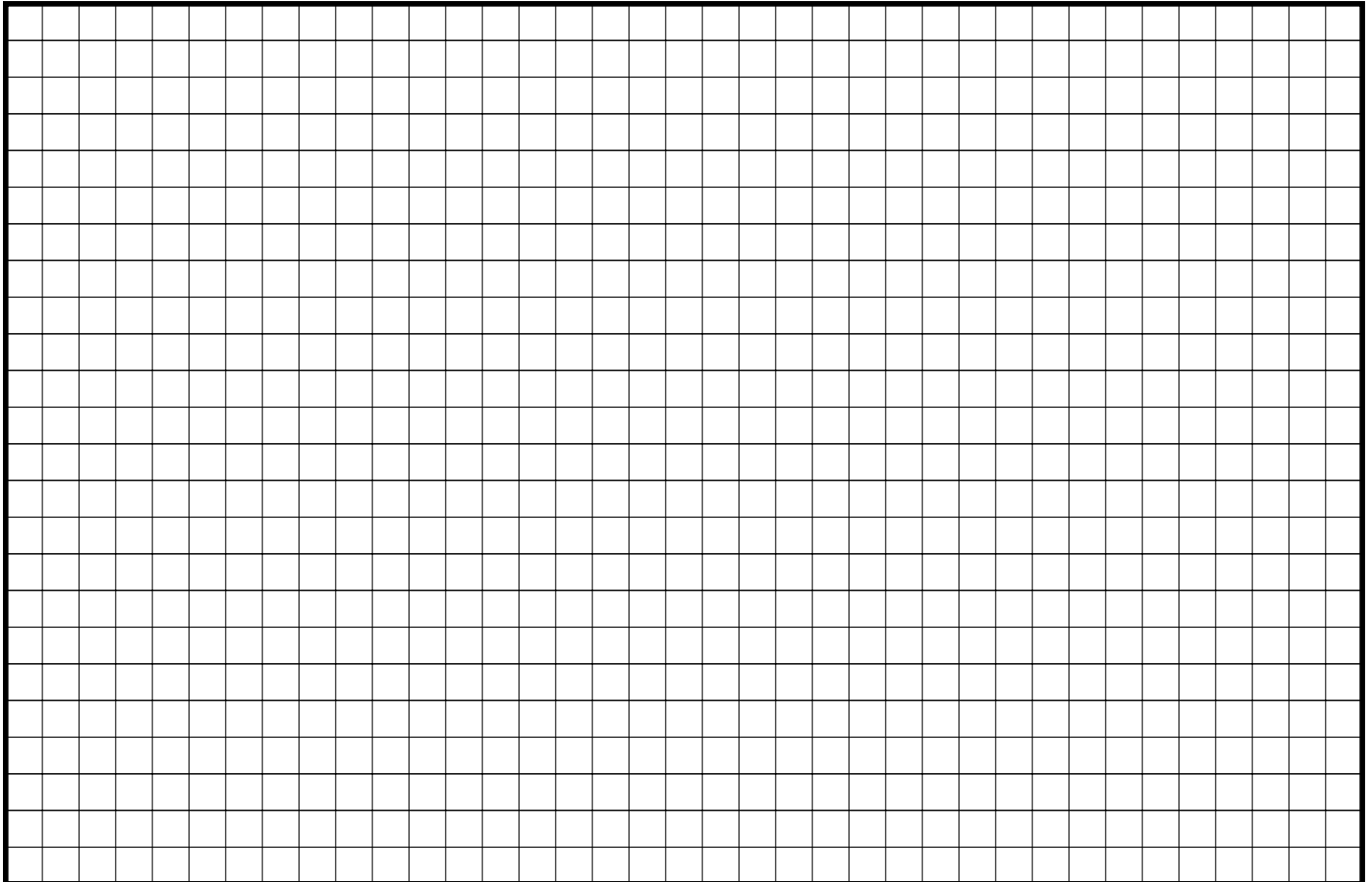
How would you respond?

_____

*Viewing *Mechanical Universe* videotapes is an enjoyable and effective way to increase your physics understanding and improve your course grade. These tapes can be viewed at the Undergraduate Library.

D. "*EXPLAINING"* FREE FALL TO AN ARISTOTELIAN

According to Giancoli, p. 83; and the *Mechanical Universe* tape *The Law of Falling Bodies*, **all bodies, regardless of their mass m, fall in a vacuum with about the same acceleration** $g = 9.8 \text{ m/s}^2$, provided they are near the surface of the Earth. Your demonstration of part C above is consistent with these claims.

1. Can you give a qualitative explanation of equal-acceleration free fall independent of mass m to an Aristotelian friend? {Y, N, U, NOT} [Your friend has an Aristotelian view (correct) that the Earth attracts the steel ball more strongly than the paper.]

2. After your explanation, suppose your Aristotelian friend says, "OK, but if you're so smart, can you tell me *WHY* bodies fall?" How would you respond?

XI. MOTION OF A KID IN A TRUCK - REVISITED
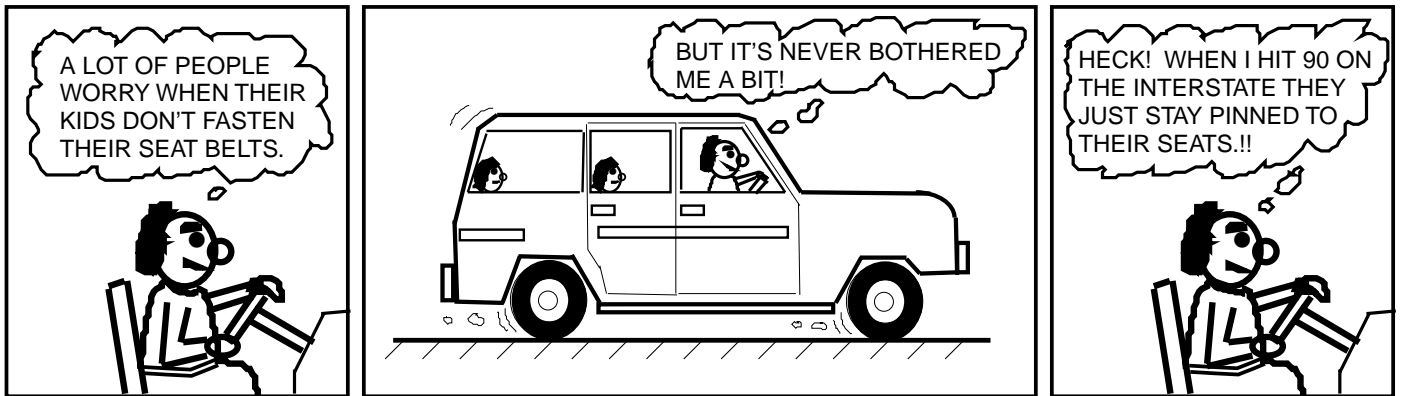
1. Recalling your work in SDI #1, can a truck driver pin kids to their seats by driving his truck at a very high constant velocity $\vec{v}$ as suggested in the cartoon above? {Y, N, U, NOT}

2. If you were a truck driver and wished to pin a kid to her seat (by control of the truck motion) what might you do? (Three time-sequential sketches with $\vec{F}$, $\vec{v}$, $\vec{a}$ vectors and clocks are worth 10 terawords.) [HINT: It may help to consider the horizontal motion of a disk in your hand.]

FORCES ON A KID SITTING IN A TRUCK MOVING SO AS TO PIN THE KID TO HER SEAT
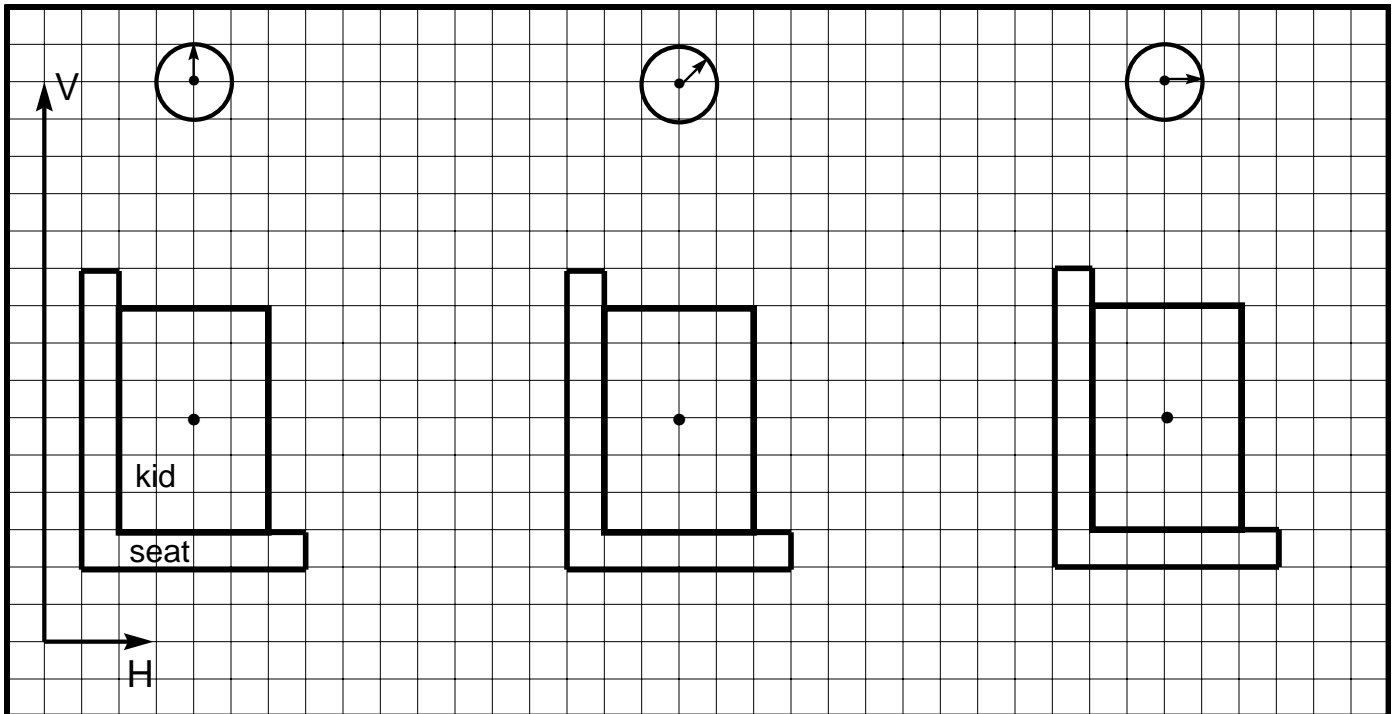
3. Is the kid sketched above in equilibrium as seen by an observer in the *Earth frame of reference*? {Y, N, U, NOT} [HINT: In answering this and latter questions please recall that in SDI labs we adopt the conventional definition of "equilibrium" such that ***a body is in equilibrium in a given reference frame if and only if its vector velocity $\vec{v}$ as observed in that reference frame is constant in time.***]

4. Is the kid sketched above in equilibrium as seen by an observer in the *Truck frame of reference*? {Y, N, U, NOT}

5. Is the Truck frame of reference an *inertial reference frame* (IRF) (i.e., a frame in which Newton's First Law is obeyed as determined by an observer riding with the frame)? {Y, N, U, NOT}

6. Is there a **NET** horizontal force vector acting on the kid? ("NET horizontal force vector" means the *vector sum* of all horizontal forces acting on the kid.) {Y, N, U, NOT}

7. Is there a horizontal force vector acting on the kid? {Y, N, U, NOT}

8. Is the kid pinned to her seat? {Y, N, U, NOT}

9. Suppose you are the kid. Can you give an operational definition of "pinned to your seat"? {Y, N, U, NOT} [HINT: What measurements might you make to determine whether or not you are pinned to your seat?]

NEWTON'S SECOND LAW

N2 (MODERN VERSION): IF A NET FORCE ACTS ON A BODY, IT WILL CAUSE AN ACCELERATION OF THAT BODY. THAT ACCELERATION IS IN THE DIRECTION OF THE NET FORCE, AND ITS MAGNITUDE IS PROPORTIONAL TO THE MAGNITUDE OF THE NET FORCE AND INVERSELY PROPORTIONAL TO THE MASS OF THE BODY.

...(N2)

$$\vec{F}_{\text{net on body}} = m_{\text{body}}\,\vec{a}_{\text{body}}$$