# SDI LAB #1. NEWTON'S FIRST AND THIRD LAWS*

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Last (Print Clearly) First (Print Clearly) ID Number

LAB SECTION ________________________LAB TABLE POSITION____________________________

*A Vulgar Mechanic can practice what he has been taught or seen done, but if he is in error he knows not how to find it out and correct it, and if you put him out of his road, he is at a stand; Whereas he that is able to reason nimbly and judiciously about figure, force and motion, is never at rest till he gets over every rub.*

Isaac Newton to Nathaniel Hawes, 25 May 1694


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## I. INTRODUCTION

This lab provides a heads- and hands-on learning experience in applying Newton's First (N1) and Newton's Third (N3) Laws to simple mechanics experiments. It will also provide practice in drawing force-motion-vector diagrams and time-sequential snapshot sketches which are very helpful in understanding mechanics. You will learn "to reason nimbly and judiciously about figure, force and motion...(thus being)...never at rest...(and getting) ...over every rub." ***As you go through this lab you may wish to refer to the NI and N3 diagrams hanging above your table*** (also on the last two pages of this manual).

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A. OBJECTIVES – To Understand:

1. how to draw color-coded force-motion-vector diagrams and time-sequential snapshot sketches;
2. *operational* definitions: vertical, horizontal, force, up, down, equilibrium;
3. the two kinds of forces considered in elementary mechanics problems: *contact (touching)* and *action-at-a-distance* (*non-touching*);
4. the application of Newton's first and third laws to simple mechanics experiments:
   a. an iron disk held stationary,
   b. an iron disk lifted vertically upward at constant velocity,
   c. an iron disk lifted vertically upward with an increasing velocity,
   d. an iron disk carried horizontally at constant velocity,
   e. a block at rest on a table,
   f. a block pushed across a table at constant velocity,
   g. a block sliding to rest on a table,
   h. a block projected horizontally into the air,
   i. a block of "dry ice" moving under various circumstances with near zero friction over a glass surface,
   j. a kid in a truck,
   k. two magnets held close together (Appendix B);
5. thought experiments;
6. idealized models;
7. the application of Newton's second law to the experiments in "4" (Appendix A).

B. HOW TO PREPARE FOR THIS LAB.

1. Study this manual **BEFORE** coming to the lab.
2. Review SDI Labs #0.1 and #0.2, and the SDI Ground Rules in SDI #0.1.
3. Review your work thus far in the course text *Physics*, 4th ed., by Douglas Giancolli, especially Chap. 2 (kinematics in one dimension), 3 (on vectors), and 4 (sections on Newton's first and third laws). If you are using another text then review similar material in that text. The following material is especially important for this lab (section numbers are for the Giancoli text):
   a. Reference Frames and Coordinate Systems, p. 20-21.
   b. Vectors, p. 23-24, 47-59.
   c. Inertial Reference Frames, p. 99.
   d. Newton's first law, p. 75 - 76.
   e. Newton's third law, p. 80 - 83.
   f. Forces: (1) non-rigorous operational definition, p. 74 - 75 (including footnote); (2) contact, p. 83, 130, 464; (3) action- at-a-distance, p. 118, 862; (4) fundamental, p. 130; (5) gravitational, p. 83, 118 - 130, 919, 947 - 952; (6) impulsive, p. 171 - 172; (7) in Newton's laws, p. 77 ff.
   g. Weight and Mass, p. 77, 83.

h. Equilibrium, p. 227 - 228 (Giancoli's treatment is ambiguous. In SDI labs we adopt the conventional definition of "equilibrium" such that ***a body is in equilibrium in a reference frame if and only if its vector velocity*** $\vec{v}$ ***as observed in that reference frame is constant in time).***

i. Operational definitions†, p. 11, 15 (question #3), 568.

j. **Sketches or Diagrams: The crucial first step in problem solving**, p. 29, 54, 62, 130, 141, 157, 205, 231, This lab should assist you in learning to draw meaningful sketches, thereby helping you to solve the physics problems in exams and homework. As stated in the ground rules below "one labeled sketch or graph is often worth a teraword (1.0 teraword $\equiv$ 1.0x$10^{12}$ words) and will often serve to indicate whether or not you really understand the physics.

† See, e.g., G. Holton and S.E. Brush, *Introduction to Concepts and Theories in Physical Science* (Princeton Univ. Press, 2nd ed., 1985) p. 176-181.

C. HOW TO DRAW A FORCE VECTOR

In order to draw a vector representing, say, the force $\vec{\mathbf{F}}$ **on** a block **by** a stick, draw a RED arrow (Vector) with the **V**ector **T**ail **O**n the **B**ody (**VTOB**) and label it $\vec{\mathbf{F}}_{\textbf{on}\text{ block }\textbf{by}\text{ stick}}$ as shown in the figure below. The vector tail should be indicated by a large dot •.

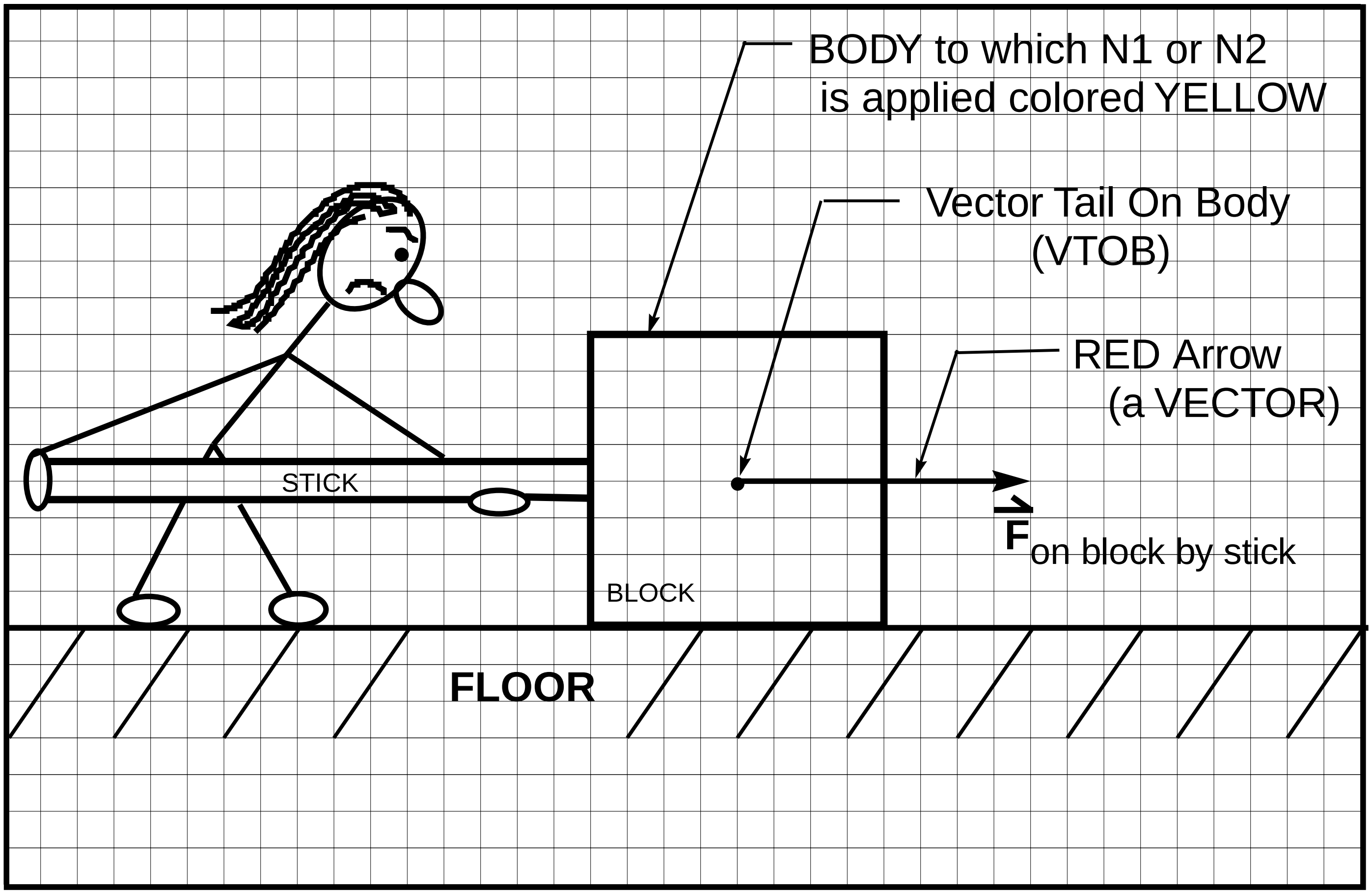


Fig. 1. A woman pushes on a stick which in turn pushes on a block, so that there is a force $\vec{\mathbf{F}}$ on the block by stick, written with subscripts as $\vec{\mathbf{F}}_{\text{on block by stick}}$. Please practice the color code by coloring the block yellow and the force vector red.

1. It is helpful in understanding Newtonian mechanics if:
   a. We *focus on just one body*, in this case the BLOCK, and then *systematically apply Newton's First (N1) or Second (N2) laws to that body.* Application of N1 or N2 requires *drawing in ALL the forces acting ON the body*, and then taking the *vector sum* of all those forces. To assist this focus, please *color the the block of Fig. 1 YELLOW*. In this way, the usual "free-body diagram" can be embedded in a "touch-body diagram" (see Fig. 2) which shows the body and all objects which *touch* the body. Most of the diagrams you will draw in SDI labs will be of the touch-body type.
   b. We distinguish between contact (*TOUCHING*) forces and non-contact (*NON-TOUCHING*, or "action-at-a-distance," or "field") forces. Thus, we do NOT say that the force is "on the block by the *woman*." The reason is that the *woman* is NOT *touching* the block, and we want to classify forces as either *touching* forces or *non-touching* forces. The force $\vec{\mathbf{F}}_{\text{on block by stick}}$ is a *touching* force which is applied **on** the block **by** the stick.

2. Is there any possibility of other significant *touching* forces acting on the block of Fig. 1? {Y, N, U, NOT}

3. Is there any possibility of some significant *non-touching* forces acting on the block of Fig. 1? {Y, N, U, NOT}

4. The length of the vector arrow should be proportional to the *magnitude* of the vector quantity. Thus in Fig. 1, *if* the magnitude of the frictional force $\vec{\mathbf{f}}_{\text{on block by floor}}$ (the use of the lower case $\vec{\mathbf{f}}$ for frictional forces is fairly conventional) is about the same as the magnitude of the force $\vec{\mathbf{F}}_{\text{on block by stick}}$, then the vector force diagram should show these two vectors with about the same lengths as shown below in Fig 2.

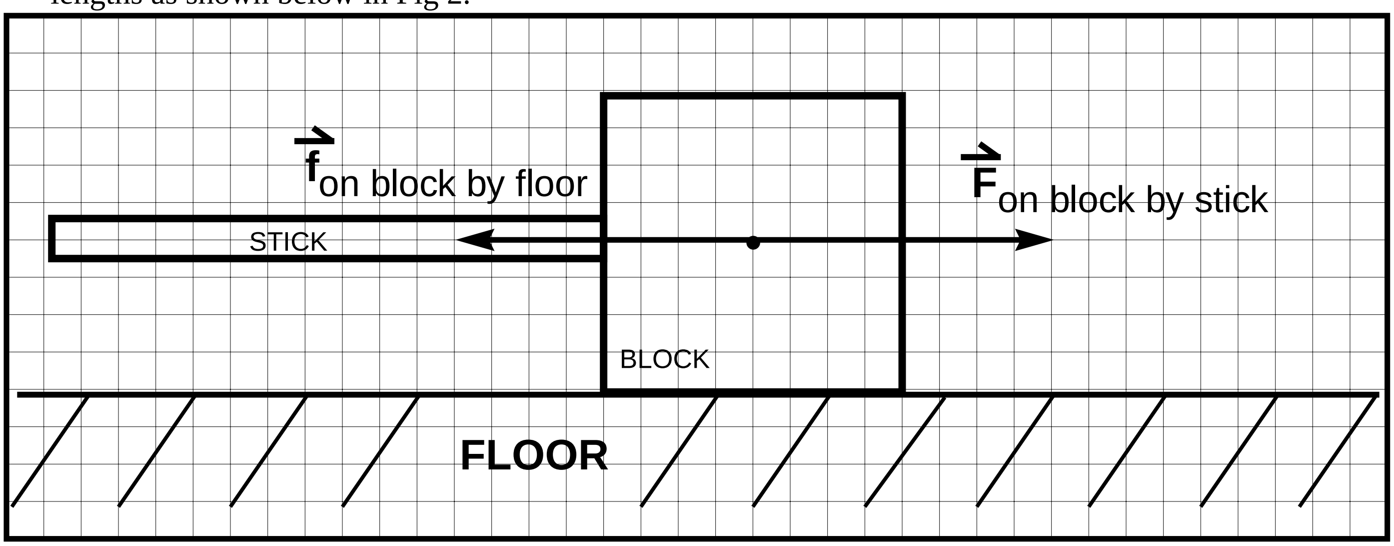


Fig. 2. A touch-body diagram showing the block and all the objects which touch the block. The *magnitudes* of the friction force $\vec{\mathbf{f}}_{\text{on block by floor}}$ and the force $\vec{\mathbf{F}}_{\text{on block by stick}}$ are about the same, as indicated by the equal lengths of the two vector arrows representing these two forces. Please practice the color code by coloring the block yellow and the force vectors red.

D. HOW TO DETERMINE THE NEWTON'S-THIRD-LAW ACTION-REACTION PAIR

You will find that Newton's-third-law action-reaction pairs are relatively easy to distinguish if you *always* use the "**on** A **by** B" designation indicated above. Then remember that **AN ACTION-REACTION PAIR NEVER ACTS ON THE SAME BODY**, and that Newton's third law can be stated succinctly as

$$\vec{\mathbf{F}}_{\text{on A by B}} = -\vec{\mathbf{F}}_{\text{on B by A}} \quad . \quad \text{.............................................................. (N3)}$$

In introductory mechanics, *one can* ***ALWAYS (!!)*** *obtain the Newton's-third-law action-reaction pair by using the "A-B-Switch" method!* (We ignore, for the moment, transient effects associated with wave propagation.)

1. In Fig. 2 above, are $\vec{\mathbf{f}}_{\text{on block by floor}}$ and $\vec{\mathbf{F}}_{\text{on block by stick}}$ a Newton's third law action-reaction pair? {Y, N, U, NOT}

2. If your answer to "1" is not "Yes," what is the Newton's Third Law reaction force to the force $\vec{\mathbf{F}}_{\text{on block by stick}}$?

3. If your answer to "1" is not "Yes," what is the Newton's Third Law reaction force to the force $\vec{\mathbf{f}}_{\text{on block by floor}}$?

E. IDEALIZED MODELS

Physics is concerned with the creation of theories or models to account for the behavior of nature. In this lab our **idealized model** of motion includes many simplifications and approximations (see Sec. VIII). For example, in this lab (a) all of our observations will be made with respect to the Earth (or Lab) frame of reference and we shall assume that *Newton's laws do apply* in this reference frame [such a frame is called an "Inertial Reference Frame" (IRF) - see the Newton's First Law Sheet at your table and on the next-to-last page of this manual], (b) we shall ignore the effects of air friction.

Another simplification is that in SDI labs 1, 2 (this lab and the next) we shall treat extended bodies (such a blocks) as *particles* in the sense that all forces on the body are considered to effectively act at a *single* point in the body (as depicted in Figs. 1, 2). Thus we ignore rotational effects. As previously indicated, we **INSIST** that you draw **V**ector **T**ails **O**n the **B**ody (**VTOB**) as in Figs. 1, 2. Since we are treating the body as a point particle, we can choose that point to be near the center of the body [latter on we shall learn that the proper point for the force vector (insofar as translational motion is concerned) is the "center of mass"].

F. HOW TO LEARN AS YOU PROCEED

You will gain more benefit from this lab if you actually perform ALL the experiments yourself. Then **discuss the experiments with your lab partners and try to figure things out for yourselves.** If you do not immediately understand an exercise, question, or problem *don't be discouraged since it may mean that you're about to learn something.* That mechanics is not an easy subject is clear from the fact that it resisted the most powerful intellects for over 2000 years. In his book *The Origins of Modern Science,* H. Butterfield comments "Of all the intellectual hurdles which the human mind has confronted and has overcome in the last fifteen hundred years the one which seems to me to have been the most amazing in character and the most stupendous in the scope of its consequences is the one relating to the problem of motion."

## II. OPERATIONAL DEFINITIONS

Before we can draw meaningful diagrams of even very simple experiments, we must be able to distinguish certain salient features of the physical world such as: position, up and down, vertical and horizontal, area and volume, north and south, equilibrium and disequilibrium, force, time, speed, velocity, acceleration. To be scientifically useful a word or words must eventually reduce to "operational definitions" which *specify the experimental significance of those words in terms of* ***well-defined measurement methods (operations).*** (Recall that in SDI Lab #0.1, you operationally defined your position in the lab frame in terms of the operations of sighting your x, y, and z positions on meter-stick-calibrated scales hung from the ceiling of the lab.)

A. VERTICAL. In the space below, give an **operational** definition of the word "vertical." [HINT #1: Examine Fig. 3 carefully. HINT #2: Can you think of any occupation in which it is essential to accurately measure or determine the vertical direction? {Y, N, U, NOT} fill in the blank __________

_______________________________________________________________________________

HINT #3: What operations do people in this occupation undertake to **measure (**or determine**)** the vertical direction?] As a guide in this first operational definition, simply fill in the blank: An *operational* definition of the word vertical is: "Vertical is the the direction ***measured (***or ***determined)*** *by:* ________________________________________________________________________________

_______________________________________________________________________________

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As stated in the SDI ground rules, "one labeled sketch or graph is often worth a teraword (1.0 teraword ≡ 1.0x$10^{12}$ words)." Show a sketch of a ***measurement*** which determines the *vertical* direction in the space below. (A good sketch should show a novice exactly how to make the measurement.)

OPERATIONAL DEFINITION OF "VERTICAL" (One sketch is worth a teraword.)

B. HORIZONTAL. In the space below give an **operational** definition of the word "horizontal."

OPERATIONAL DEFINITION OF "HORIZONTAL" (One sketch is worth a teraword.)

C. FORCE. In the space below give an operational definition of the word "force." (The difficult task of constructing a rigorous operational definition of force will be addressed in some courses in SDI #6, *Newton's Second Law Revisited*. For now a non-rigorous definition of "force" will be helpful.) [HINT: Think of ways to ***measure*** force.]

OPERATIONAL DEFINITION OF "FORCE" (One sketch is worth a teraword.)

D. VERTICAL AND HORIZONTAL AXES. In all the sketches for this lab, we INSIST that you show a reference-frame axes labeled **V** (Vertical) and **H** (Horizontal) as shown in Fig. 3. Note that one must distinguish carefully between the **V**-**H** and y-x axes. The orientation of the latter is arbitrary, although in Fig. 3 the y-x orientation has been chosen to be the same as the **V**-**H** orientation.

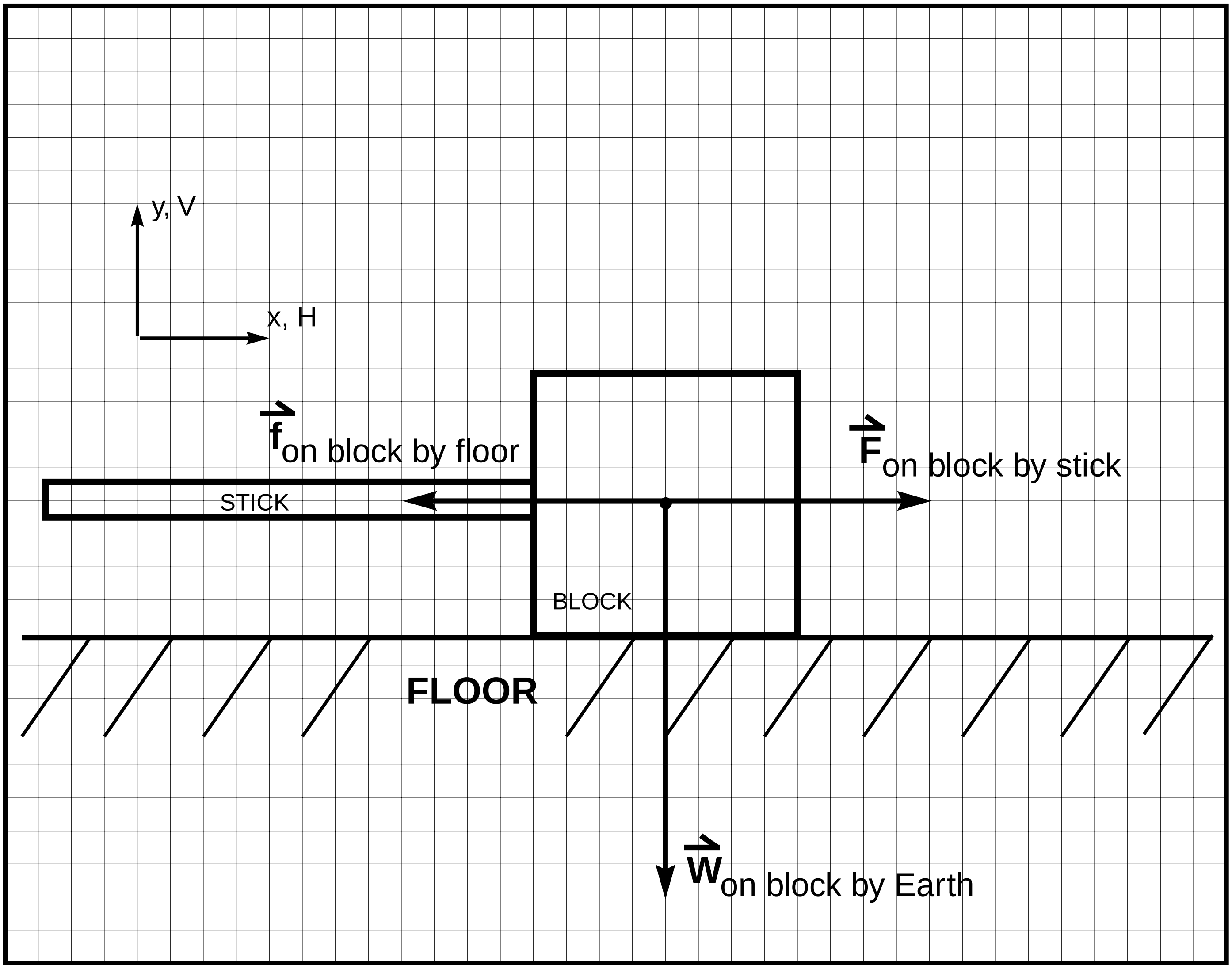


Fig. 3. A touch-body diagram of a block acted upon by several forces. Only the block and other objects which are touching the block are shown. Note the V–H (Vertical–Horizontal) reference axes. The gravitational force $\vec{\mathbf{F}}_{\text{on block by Earth}}$ is just the weight of the block and so is called here $\vec{\mathbf{W}}_{\text{on block by Earth}}$. Please practice the color code by coloring the block yellow and the force vectors red.

1. Considering ONLY FORCES ACTING **ON** THE BODY, and assuming that the block's vertical velocity with respect to (wrt) the lab frame is constant (at zero) in time, is there a missing force vector in Fig. 3? {Y, N, U, NOT} (Justify your answer in terms of N1. If you have answered "Yes" then show the force vector in Fig. 3 and label it in the usual $\vec{\mathbf{F}}_{\text{on A by B}}$ manner.

2. Considering N1, can you describe the motion of the block in Fig. 3? {Y, N, U, NOT}

E. HOW WOULD YOU TELL "UP" FROM "DOWN"?

OPERATIONAL DEFINITION OF "UP" AND "DOWN" (One sketch is worth a teraword.)

F. EQUILIBRIUM. An *operational definition* of "equilibrium" can be stated as: **"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**, provided that we operationally define the word "velocity." We shall defer the construction of an operational definition of velocity until the SDI Lab #2 pre-lab assignment. (When rotational motion is considered, a more complete definition requiring that both the linear $\vec{v}$ and angular $\vec{\omega}$ velocities be constant is required.) Please don't confuse the *state* of equilibrium as operationally defined above with the force conditions required by Newton's laws to produce that state ***IF*** *the body and the observer are in an Inertial Reference Frame (IRF).* Thus, please do NOT state that "equilibrium" is *defined* to mean that the summation of all forces acting on a body is zero.

Sketch a diagram illustrating the above operational definition of equilibrium in a given Reference Frame (RF) in the space on the next page. [HINT: Carefully examine the Newton's First Law diagram hanging above your table (and on p. 50 of this manual).]

OPERATIONAL DEFINITION OF EQUILIBRIUM IN A REFERENCE FRAME (RF)

**III. FORCES EXERTED ON A DISK BY YOUR HAND**

A. DISK AT REST

Hold an iron ***disk*** (a standard lab disk of mass1-kg) stationary in the lab frame on the palm of your hand at about eye level. In the space below show **ALL** the force vectors (colored red !) acting **on the disk (**colored yellow!**)**. Draw the velocity vector (colored green) if you think it exists or as a green dot on the disk if you think it is zero.

You will move a long way towards the Newtonian world if you can determine **ALL** the forces acting ON a BODY. To do this successfully always ask yourself TWO KEY QUESTIONS*****:

**(1) What objects *TOUCH* the BODY?** Only these can transmit **contact forces**. (It must be realized that *touching* is a necessary but not a sufficient condition for the transmission of a contact force, i.e., two bodies *may* touch without there being significant contact forces between them.)

**(2) What *non-touching*** ("action-at-a-distance") **forces act on the BODY?** Usually only the gravitational force $\vec{\mathbf{F}}_{\text{on body by Earth}}$ (i.e., the "weight," often labeled $\vec{\mathbf{W}}_{\text{on body by Earth}}$) is significant.

FORCES ON A DISK HELD STATIONARY IN YOUR HAND

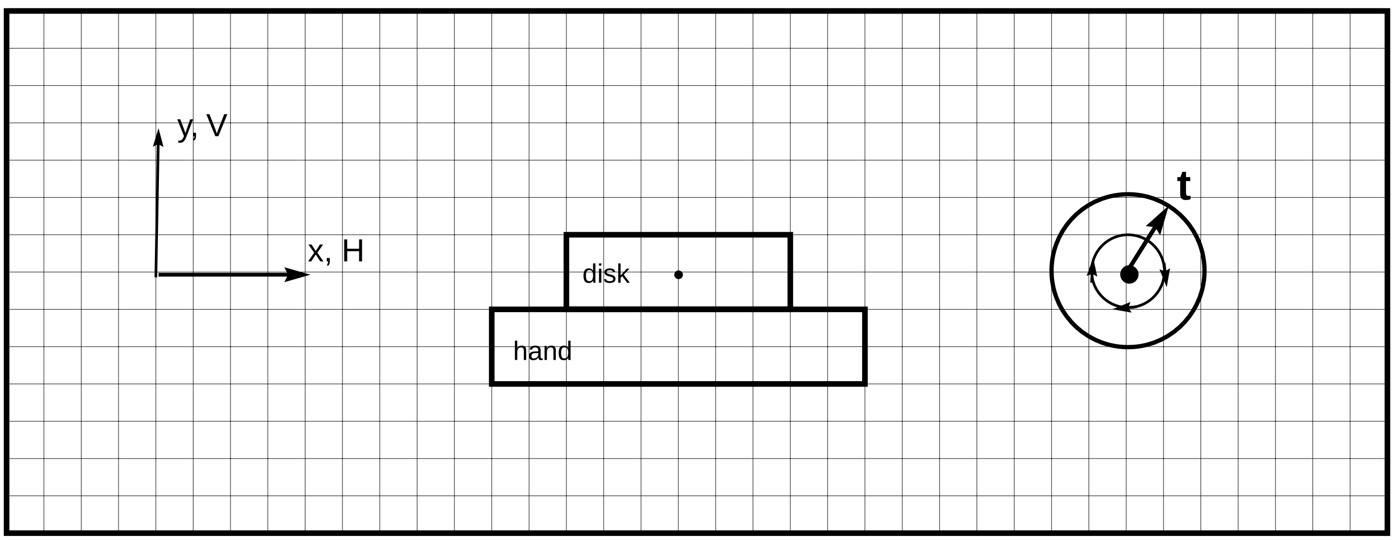


Fig. 4. A touch-body FRONT VIEW of a disk held stationary on your hand in the lab frame. The clock symbol is meant to show that the spatial positions of the disk and hand are constant in time.

Near the surface of the Earth the 1.0 kg iron disk weighs 9.8 N or 2.2 lb (see Giancoli, p. 83). Complete the following sentences which describe the above simple experiment:

1. A downward force of magnitude 9.8 N is exerted on the disk by________________ .

(It may help in answering subsequent questions to label the force as $\vec{\mathbf{W}}_{\text{on A by B}}$ in the above diagram.)

2. An upward force of magnitude__________ is exerted on the_________by the hand. (It may help in answering subsequent questions to label the force as $\vec{\mathbf{N}}_{\text{on A by B}}$ in the above diagram.)

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***** This *touch method* of determining the forces is due to Joan Heller and Fred Reif (HR) who showed its remarkable effectiveness in carefully controlled experiments at Berkeley. The "HR Strategy" also involves checking to make sure that $\vec{\mathbf{F}}_{\text{net on the body}}$ and the acceleration $\vec{\mathbf{a}}$ of the body are in the same direction, as will be discussed in SDI Lab #2.

3. Do the two forces $\vec{\mathbf{W}}$ and $\vec{\mathbf{N}}$ constitute a Newton's-third-law (N3) action-reaction pair? {Y, N, U, NOT} [HINT: Please carefully **STUDY** (a) "How to Determine the Newton's Third Law Action-Reaction Pair," Sec. I-D, and (b) the *Newton's Third Law diagram* hanging above your table (or at the back of this manual) before answering this question!]

4. That forces $\vec{\mathbf{W}}$ and $\vec{\mathbf{N}}$ are equal and opposite is an example of Newton's _______law. Does the equality of these forces depend on the fact that the disk has a constant (zero) vertical velocity? {Y, N, U, NOT}

5. The reaction force (call it $\vec{\mathbf{F}}_5$) to force $\vec{\mathbf{N}}$ is a force of magnitude_______, exerted on __________by __________. Its direction is ________________________________________ .

(It may help in answering subsequent questions to label the force as $\vec{\mathbf{F}}_{5 \text{ on A by B}}$ in the diagram below. The "5" refers to the number of this question."

N3 ACTION-REACTION PAIR $\vec{\mathbf{N}}$ AND $\vec{\mathbf{F}}_5$ (A labeled sketch of the N3 pair is worth a teraword.)

6. That forces $\vec{\mathbf{N}}$ and $\vec{\mathbf{F}}_5$ are equal and opposite is an example of Newton's ______ law. Does the equality of these forces depend on the fact that the disk has a constant (zero) vertical velocity? {Y, N, U, NOT}

7. The reaction force (call it $\vec{\mathbf{F}}_7$) to the force $\vec{\mathbf{W}}$ is a force of magnitude____ , exerted on the ___________ by the__________. Its direction is ___________________________________.

(It may help in answering subsequent questions to label the force as $\vec{\mathbf{F}}_{7 \text{ on A by B}}$ in the diagram below.)

N3 ACTION-REACTION PAIR $\vec{\mathbf{W}}$ AND $\vec{\mathbf{F}}_7$ (A labeled sketch of the N3 pair is worth a teraword.)

8. In this experiment, what are the forces which are *directly felt* by your hand? (Indicate them as $\vec{\mathbf{F}}_{\text{on A by B}}$.)

B. LIFT THE DISK VERTICALLY UPWARD AT *CONSTANT* SPEED

FORCES ON A DISK LIFTED VERTICALLY UPWARD AT CONSTANT SPEED

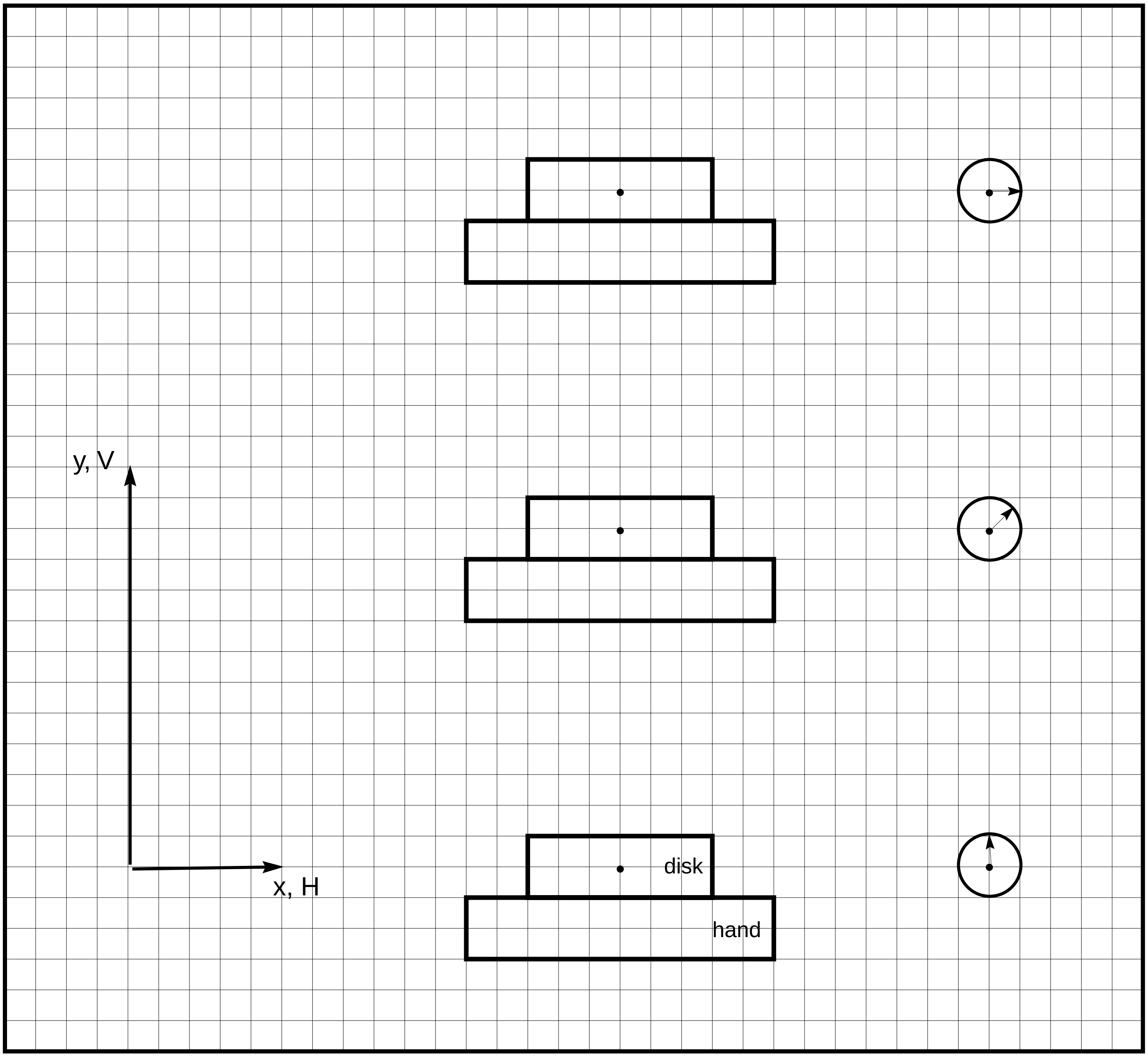



Fig. 4. Snapshot sketches of a disk at equal time intervals *during its motion.* The disk is lifted vertically upward at a *constant* speed with respect to (wrt) the lab frame. As a result, the disk travels the same distance in the second time interval as it did in the first time interval.

Show **ALL** the force vectors (red) acting **on the disk** at these three positions. Show the vector tails as dots "•" near the center of the disk.

Draw velocity vectors (green) at each of the three positions. Again, show the vector tails as dots "•" on the disk, but *offset the dots from the center* so that they do not lie on top of the force vector tails.

Since your 3 sketches show the disk at 3 *instants of time* ("clock readings") during its motion, these drawings might be called "snapshot sketches" because they're similar to snapshots taken with a camera. Henceforth, in SDI labs we shall often refer to such drawings as "snapshot sketches."

1. Is the disk sketched above in equilibrium in the lab frame? {Y, N, U, NOT} [HINT: Please consider the *definition* of "equilibrium" in Sec. II-F before answering this question: ***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*.**]

2. How would the answers you gave in Sec. III-A, parts 1-8 (the disk stationary in the palm of your hand) change for this case in which the disk is moving at a constant non-zero vertical velocity in the palm of your hand?

3. Specifically, for the non-zero constant vertical velocity case, is the force on the block by the hand equal to the force on the hand by the block? {Y, N, U, NOT} This is an example of Newton's _______ law.

C. LIFT THE DISK VERTICALLY UPWARD AT *UNIFORMLY INCREASING* SPEED

FORCES ON A DISK LIFTED VERTICALLY UPWARD AT A UNIFORMLY INCREASING SPEED

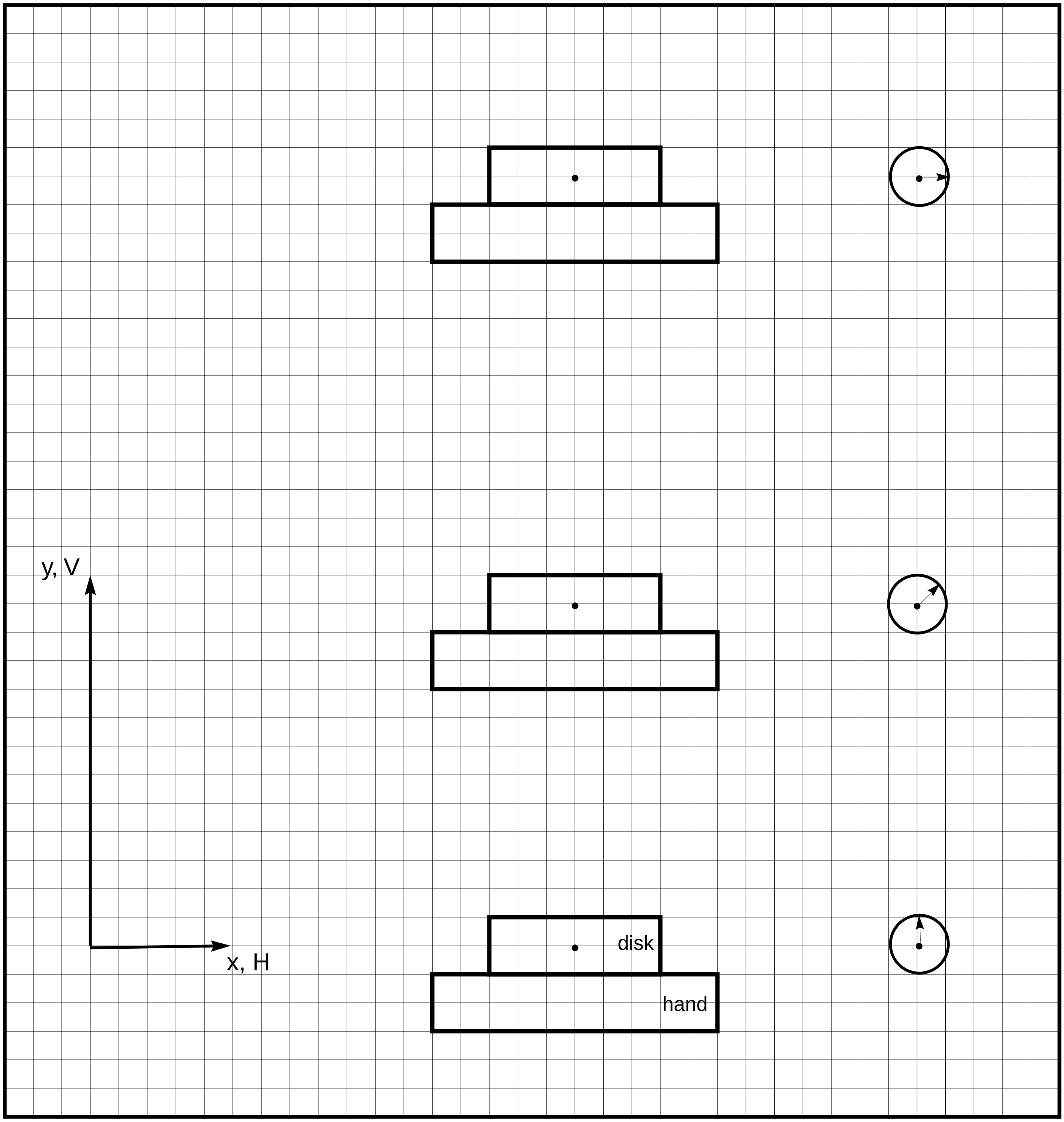



Fig. 5. Snapshot sketches of a disk at equal time intervals *during its motion*. The disk is lifted vertically upward at a *uniformly increasing speed* with respect to the lab frame. As a result, the disk travels a greater distance in the second time interval than in the first time interval.

Lift the disk vertically upward so that its speed wrt the lab frame continuously and *UNIFORMLY increases*, i.e., the velocity increases continuously by equal amounts in equal intervals of time (this is the definition of motion at constant acceleration). Fig. 5 shows the disk and your hand **while they are in motion** at 3 positions: *near the start, middle, and end of the increasing velocity* $\vec{\mathbf{v}}$ *motion.* Show **ALL** the force vectors acting **on the disk** at these 3 positions. Draw velocity vectors at each of the 3 positions.

1. Is the disk sketched above in equilibrium in the lab frame? {Y, N, U, NOT} [HINT: Please consider the *definition* of "equilibrium" in Sec. II-F before answering this question: ***a body is in equilibrium in a given reference frame if and only if its vector velocity*** $\vec{\mathbf{v}}$ ***as observed in that reference frame is constant in time***.]

2. Is the force exerted on the disk by your hand equal and opposite to the force exerted on the disk by the Earth? {Y, N, U, NOT} (This illustrates Newton's________law.)

3. Is the force exerted on the disk by the Earth equal and opposite to the force exerted on the Earth by the disk? {Y, N, U, NOT} (This illustrates Newton's ________law.)

4. Is the force exerted on the disk by your hand equal and opposite to the force exerted on your hand by the disk? {Y, N, U, NOT} (This illustrates Newton's_________ law.)

5. Is it necessary that the force exerted on the disk by your hand be continuously increasing with time in order that the disk's velocity be continuously increasing in time? {Y, N, U, NOT}

6. In this experiment, what are the forces which are *directly felt* by your hand? (Indicate them as $\vec{\mathbf{F}}_{\text{on A by B}}$.)

D. CARRYING THE DISK AT CONSTANT HORIZONTAL VELOCITY

Holding the disk at about eye level walk about 6 ft (2 m) at a nearly constant horizontal velocity $\vec{\mathbf{v}}$ (i.e., in a straight line at constant speed). The figure below shows the disk at three positions in its constant $\vec{\mathbf{v}}$ motion. Show **ALL** the force vectors acting **on the disk** at these 3 positions. Draw velocity vectors at each of the 3 positions. Here again, these are "snapshot sketches."

FORCES ON A DISK CARRIED AT CONSTANT HORIZONTAL VELOCITY

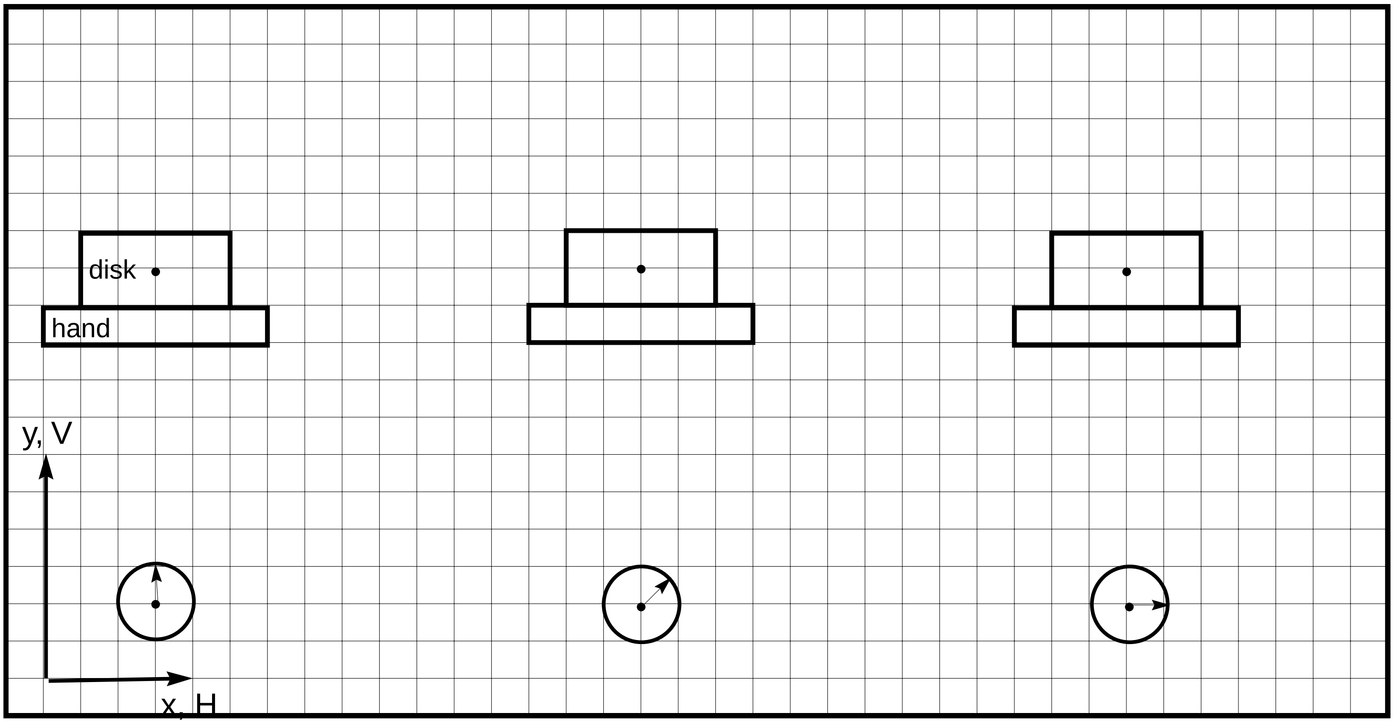



Fig. 6. Snapshot sketches of a disk at equal time intervals *during its motion*. The disk is carried horizontally at a *constant* speed with respect to the lab frame. As a result, the disk travels the same distance in the second time interval as it did in the first time interval.

1. Is the disk sketched above in equilibrium in the lab frame? {Y, N, U, NOT} [HINT: Please consider the *definition* of "equilibrium" in Sec. II-F before answering this question: ***a body is in equilibrium in a given reference frame if and only if its vector velocity*** $\vec{\mathbf{v}}$ ***as observed in that reference frame is constant in time***.]

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

3. Is there a horizontal force acting on the disk? {Y, N, U, NOT}

4. If your answer to "3" is "Yes" explain how your answers to "2" and "3" are consistent. If your answer to "3" is "No," can you think of any special way of carrying the disk *at constant* $\vec{\mathbf{v}}$ *with respect to the lab frame of reference* so that there *would* be a horizontal force on the disk? {Y, N, U, NOT}

5. Is the net force exerted on the disk by your hand equal and opposite to the force exerted on the disk by the Earth? {Y, N, U, NOT} (This illustrates Newton's_______ law.)

6. Is the force exerted on the disk by the Earth equal and opposite to the force exerted on the Earth by the disk? {Y, N, U, NOT} (This illustrates Newton's_________law.)

7. Is the net force exerted on the disk by your hand equal and opposite to the net force exerted on your hand by the disk? {Y, N, U, NOT} (This illustrates Newton's __________ law.)

8. In this experiment, what are the forces which are *directly felt* by your hand? (Indicate them as $\vec{\mathbf{F}}_{\text{on A by B}}$.)

## IV. FORCES EXERTED ON A WOODEN BLOCK BY A TABLE

A. BLOCK AT REST

Place a wooden block so it is at rest (with respect to the lab frame) on a table. The figure below shows the block and the table top. Show ALL the force vectors acting on the block. Draw velocity vectors if you think they exist.

FORCES ON A BLOCK AT REST ON A TABLE

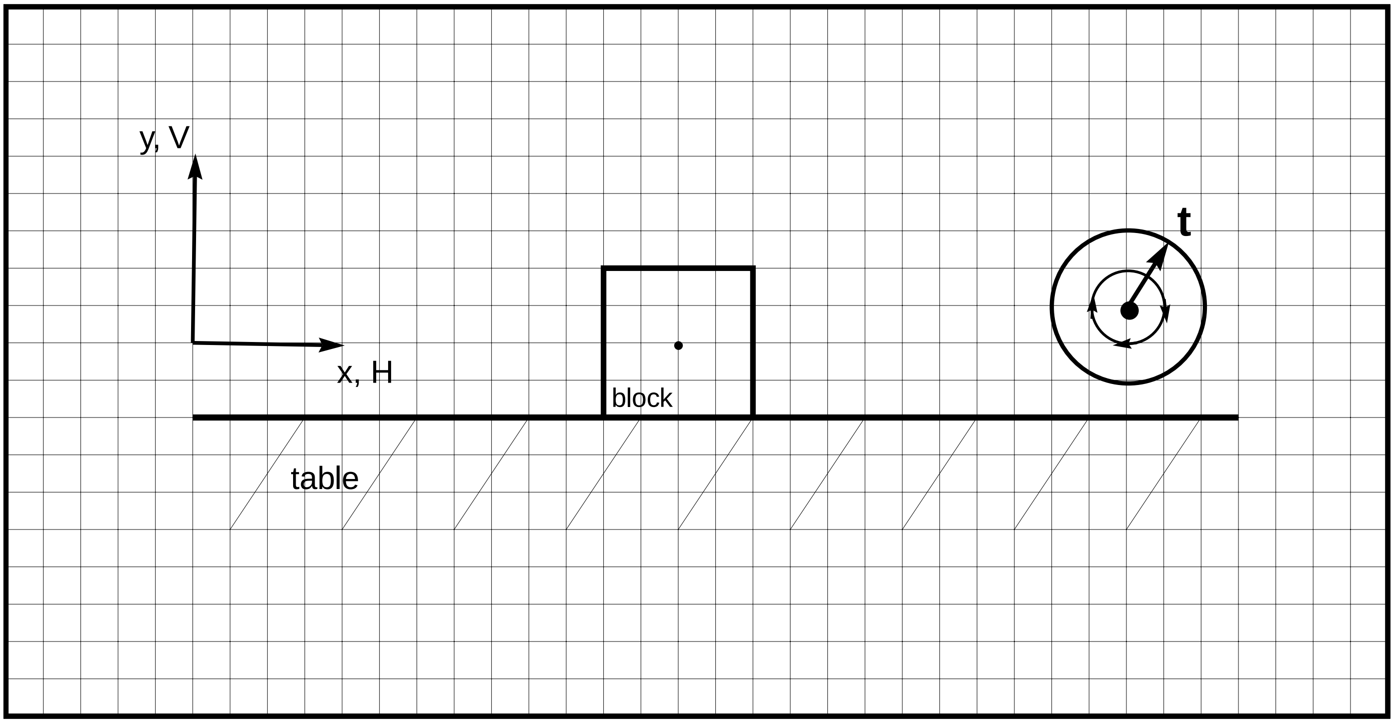



Fig. 7. A touch body FRONT VIEW of a block at rest on a table in the lab frame. The clock symbol is meant to show that the spatial positions of the block and table are constant in time.

1. Is the block sketched above in equilibrium in the lab frame? {Y, N, U, NOT} HINT: Please consider the *definition* of "equilibrium" in Sec. II-F before answering this question: ***a body is in equilibrium in a given reference frame if and only if its vector velocity*** $\vec{\mathbf{v}}$ ***as observed in that reference frame is constant in time*****.**]

2. Is the force exerted on the block by the table equal and opposite to the force exerted on the block by the Earth? {Y, N, U, NOT}***** (This is an example of Newton's_______law.

________________________________________________________________________________-

*****Here and throughout this lab, please recall the and abide by the ground rules for SDI labs set forth in the Introduction and recall that a curly bracket {.......} indicates that you should **ENCIRCLE** O a response within the bracket and then, we **INSIST**, briefly **EXPLAIN** or **JUSTIFY** your answers in the space provided on these sheets. The letters {Y, N, U, NOT} stand for {Yes, No, Uncertain, None Of These}.

B. BLOCK PUSHED AT CONSTANT VELOCITY

Push the block across the table with a nearly constant horizontal velocity $\vec{\mathbf{v}}$. Fig. 7 shows your hand and the block at 3 positions on the table *while it is in motion*: near the start, middle, and end of the constant-velocity motion. Show **ALL** the force vectors acting on the block at these three positions. Draw velocity vectors at each of the three positions if you think they exist.

FORCES ON A BLOCK PUSHED AT CONSTANT VELOCITY ON A TABLE

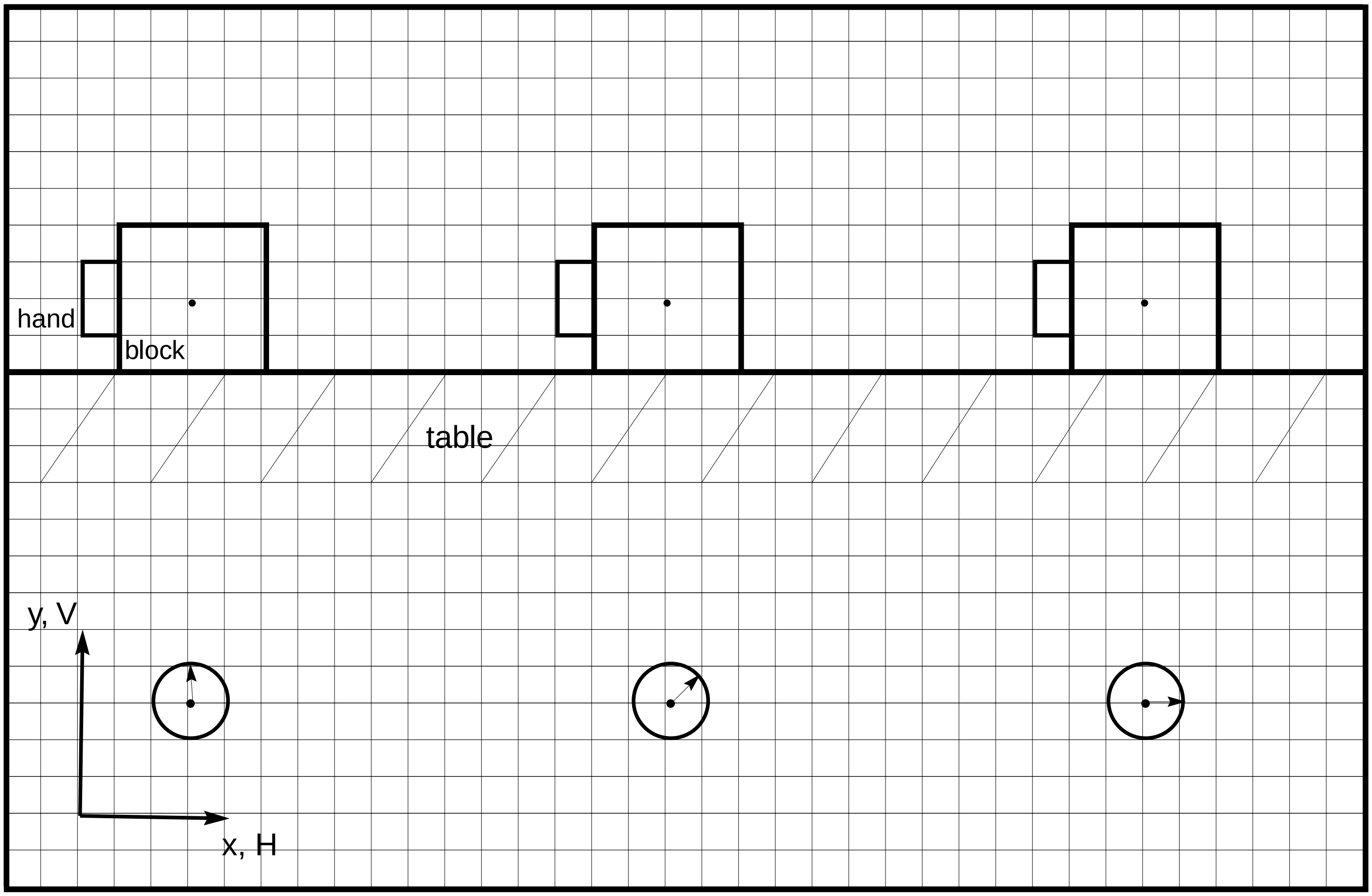



Fig. 7. Snapshot sketches of a block at equal time intervals *during its motion*. The block is pushed across a table at a constant horizontal velocity $\vec{\mathbf{v}}$ with respect to the lab frame. As a result, the block travels the same distance in the second time interval as it did in the first time interval.

1. Is the block sketched above in equilibrium in the lab frame? {Y, N, U, NOT} [HINT: Please consider the *definition* of "equilibrium" in Sec. II-F before answering this question.]

2. Is there a **NET** horizontal force vector acting on the block? (Remember that NET horizontal force *means the vector sum of all the horizontal forces.*) {Y, N, U, NOT}

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

4. Is the **NET** force exerted on the block by the table equal and opposite to the force exerted on the block by your hand? {Y, N, U, NOT} [Hint: A labeled sketch in one of the snapshots of Fig. 7 would be worth a teraword!]

5. How does the force on the block by the hand compare with the force on the hand by the block?

C. BLOCK SLIDING TO REST

Give the block a tap (impulsive force) with your hand in a horizontal direction such that it slides about 3 ft (1 m). In Fig. 8 below show **ALL** the force vectors acting on the block at the 3 positions shown. Draw velocity vectors at each of the three positions.

FORCES ON A BLOCK SLIDING TO REST ON A TABLE

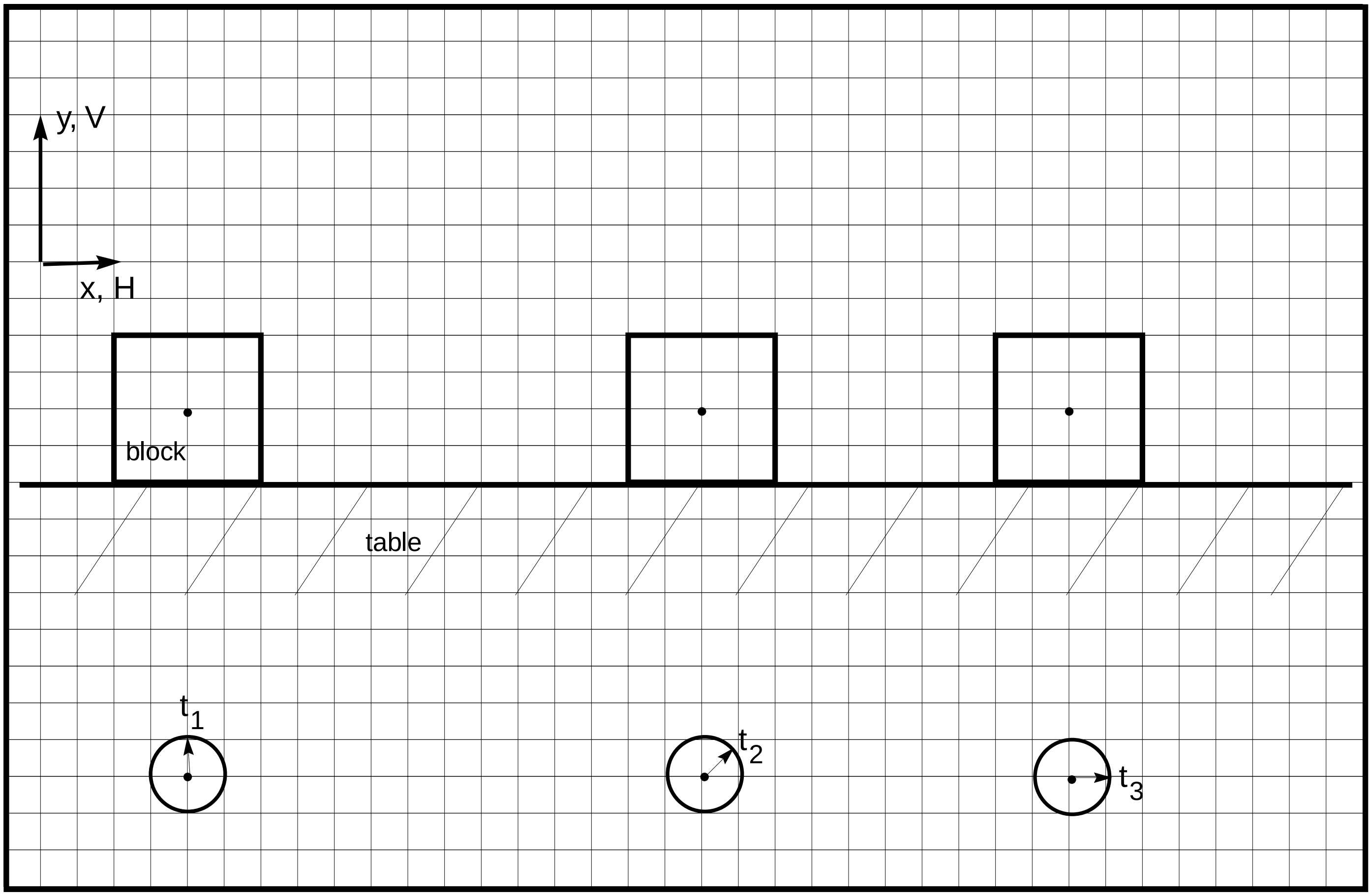



Fig. 8. Snapshot sketches of a block at equal time intervals. The block is given an initial tap so that it slides to rest on the table. The block is shown on the table at 3 positions *after it has left your hand and* ***while it is in motion***: *near the start, near the middle, and near the end of its slide.* That the block is slowing down is shown by the fact that the displacement during the second time interval ($t_3$ - $t_2$) is less than the displacement during the first time interval ($t_2$ - $t_1$). (Compare the snapshot sketches for Ground Rule #5 in Sec. I- C of SDI #0.1 where a block is speeding up.)

1. Is the block sketched above in equilibrium in the lab frame? {Y, N, U, NOT} [HINT: Please consider the *definition* of "equilibrium" in Sec. II-F before answering this question: ***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*.**]

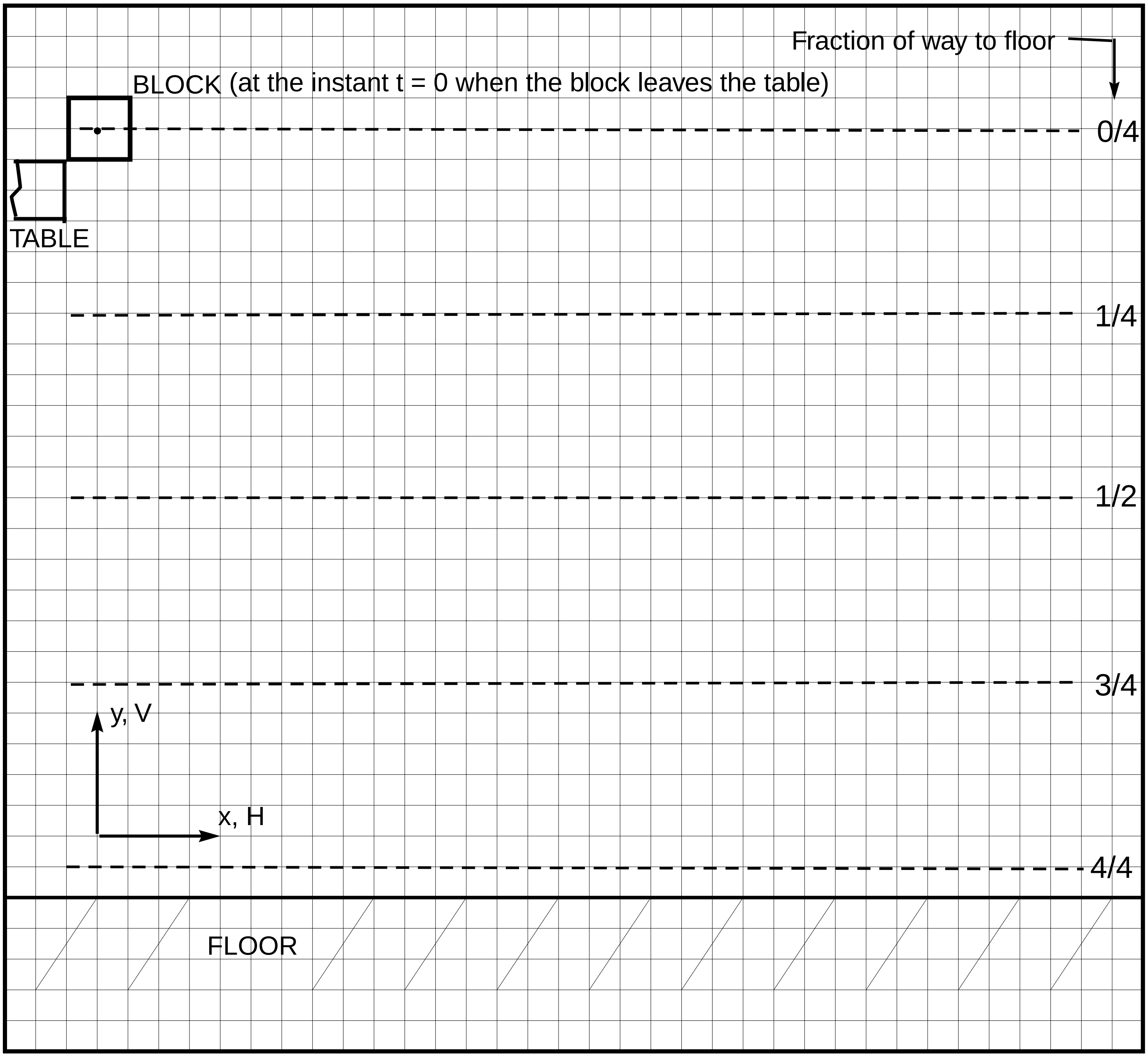
2. Is the **NET** force exerted on the block by the table equal and opposite to the force exerted on the block by the Earth? (here "NET force exerted on the block by the table" means *the vector sum* of all force components exerted on the block by the table). {Y, N, U, NOT} [Hint: A labeled sketch in one of the snapshots of Fig. 8 would be worth a teraword!]

3. Is the NET force exerted on the block by the table equal and opposite to the NET force exerted on the table by the block? {Y, N, U, NOT} This is an example of Newton's________Law.

D. BLOCK PROJECTED INTO THE AIR

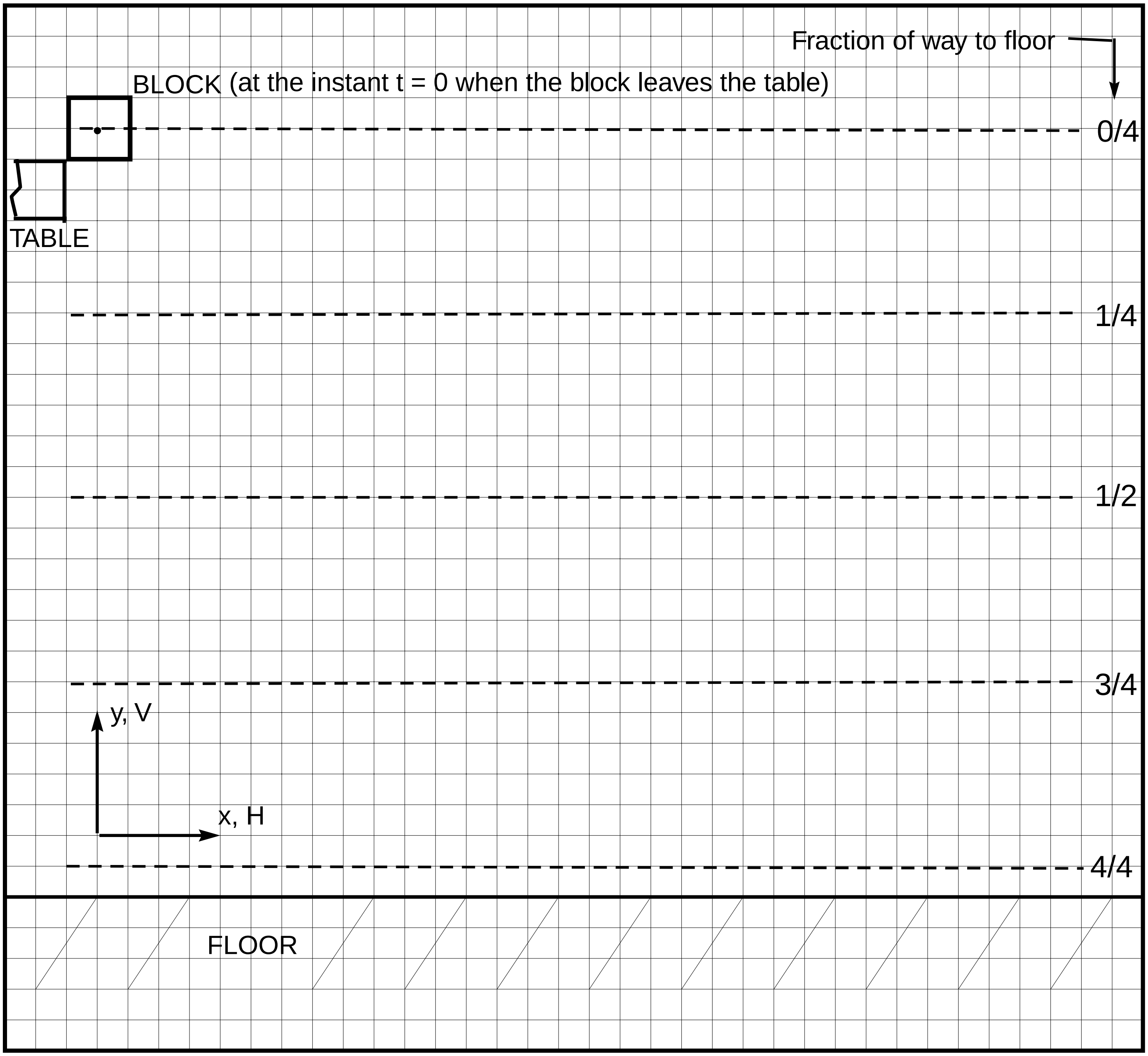
Suppose you were to give the block a vigorous push (an "impulsive force," i.e., a force acting only over a very small time interval $\Delta t$ ) with your hand in a horizontal direction so that it slides across the table, is projected horizontally into the air, and hits the floor at a distance from the base of the table which is about equal to the height of the table. In the space below show *your prediction* for the **path** of the block *along the table top and through the air to the floor.* (*Always* represent paths as *continuous* straight or curved lines, *not* a series of arrows.)

PREDICTION: PATH OF BLOCK PROJECTED HORIZONTALLY INTO THE AIR




1. Now have your lab partner *perform the above experiment* **AFTER** you have stationed yourself so that you can carefully observe the path of the block from a position such that your line of sight is perpendicular to the plane of the motion. **Draw the observed path as a continuous line in the space on the next page.** Does it agree with your prediction? {Y, N, U, NOT}

EXPERIMENTAL RESULTS: PATH OF BLOCK PROJECTED HORIZONTALLY INTO THE AIR.




2. In the above figure, sketch the block at 4 positions along the path after it has left the table: *at the* ***instant*** *it leaves the table*; 1/4, 1/2, and 3/4 of the distance to the floor. At these (or any other positions along the path), is there any necessary relationship between the direction of the path and the direction of of the block's velocity $\vec{\mathbf{v}}$ ? {Y, N, U, NOT}

3. Draw horizontal $\vec{\mathbf{v}}_\mathbf{x}$, vertical $\vec{\mathbf{v}}_\mathbf{y}$, and resultant $\vec{\mathbf{v}}_\mathbf{R}$ (same as $\vec{\mathbf{v}}$ in "2") velocity vectors at these 4 positions. Here it is convenient to show the velocity vector tails at the *center* of the block.

4. Show **ALL** the force vectors acting **on the block** at these 4 positions with their tails on the block but displaced from its center. (At these low speeds the frictional force on the block by the air is negligible.)

5. Is the block sketched above in equilibrium in the lab frame? {Y, N, U, NOT} [HINT: Please consider the *definition* of "equilibrium" in Sec. II-F before answering this question: ***a body is in equilibrium in a given reference frame if and only if its vector velocity*** $\vec{\mathbf{v}}$ ***as observed in that reference frame is constant in time*.**]

6. Is there a **NET** *horizontal* force acting on the block? {Y, N, U, NOT}

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

8. Is there a **NET** *vertical* force acting on the block? {Y, N, U, NOT}

9. Is there a *vertical* force acting on the block? {Y, N, U, NOT}

10. At the ***instant*** (call it t = 0) *that the block leaves the table* (first snapshot above), does the block (regarded as a point particle, i.e., in the limit as the block becomes *very small* with respect to other lengths in the experiment):

a. experience a vertical force? {Y, N, U, NOT}

b. have a vertical acceleration? {Y, N, U, NOT}

c. have a vertical velocity? {Y, N, U, NOT}

## V. BLOCK PROJECTED INTO THE AIR - COMPUTER INVESTIGATION

*Please complete the preceding Section IV "Forces Exerted on a Wooden Block ....." 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. *Trajectory* displays a ball, but the physics of a projected block is the same as that of a projected ball for the experiment of IVD.

Note that the range of selectable values for the the mass of the ball (block) m (0.03 - 0.20 kg), launch angle θ (0° - 180°), launch height H (0 - 3m), and launch speed $v_o$( 0 - 10 m/s) span the actual values as experienced in the lab. Thus simulations of the motion investigated in Sec. IV-D 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 $\vec{\mathbf{a}}$ due to the earth's gravitational force $\vec{\mathbf{W}}_{\text{on block by Earth}}$ 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 block on the moon (g = 1.7 $m/s^2$) or on Jupiter (g = 19 $m/s^2$).

1. Pull down the Options Menu and select all the options except *Track Ball.* Select *Background Image* if you wish to view a sunset. Note that the grid lines are 1.0 m apart. Select a Zoom setting of 400 to enlarge the picture on the screen. Simulate the experiment done in Sec. IV-D by setting the time t = 0, g = 9.8 $m/s^2$, m = 0.10 kg, launch angle θ = 0.00°, and launch height H = 1.00 m. Set the launch speed $v_{ox}$ such that the Range R = 1.0 m. Here R is defined to be the *horizontal* distance moved from takeoff to landing as indicated by the black trajectory curve. For future reference, record in the blank the required value $v_{ox}$ =_______ m/s.

   a. Click on the Action "Throw Ball." Indicate the computer's reading of the time interval T =_________sec for the block to traverse this trajectory. *Qualitatively* describe the time dependence of the horizontal, vertical, and resultant velocities:

   (1) $\vec{\mathbf{v}}_x$

   (2) $\vec{\mathbf{v}}_y$

   (3) $\vec{\mathbf{v}}_R$

   b. Are the above time dependencies above consistent with your snapshot sketches in Sec. IV-D? (Use the time slider to move the ball to any point on its trajectory. Select the option *Track Ball* to keep all vectors visible throughout the trajectory.) {Y, N, U, NOT} If your answer is not "Yes," please justify the lack of consistency.

---

† Written by Randall Bird for *Project Socrates.* Bird's animations, runnning 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. The computer picture at t = 0.00 sec duplicates the conditions of question #10 in Sec. IV-D: the ball/block (considered as a point particle) is shown at the instant it leaves the table. Are your responses to #10 consistent with the computer picture? {Y, N, U, NOT} If your answer is not "Yes," please justify the lack of consistency.

2. Return to the parameter values of "1". Can you predict the qualitative influence on the trajectory if the mass m is increased to 0.20 kg, *leaving all the other parameters the same*?
{Y, N, U, NOT}

a. Increase the mass m as above and watch the position of the black trajectory curve. Is your prediction verified? {Y, N, U, NOT} Can you explain the results? {Y, N, U, NOT}

3. Return to the parameter values of "1", except set the Zoom at 200. Indicate in the blank your prediction for the time T =_______sec taken for the block to traverse a longer trajectory with a range R = 4.0 m (obtained by increasing $v_{ox}$, *leaving all other parameters the same.*

a. Increase the range R as above by increasing the launch speed $v_o$. Click on the Action "Throw Ball." Is your prediction verified? {Y, N, U, NOT} Can you explain the results?
{Y, N, U, NOT}

4. Return to the parameter values of "1". Can you predict the qualitative influence on the trajectory of decreasing the value of g to its value on the moon, $g = 1.7$ m/s$^2$, *leaving all other parameters the same*.? {Y, N, U, NOT}

.

a. Decrease g as above and click on "Throw Ball." Adjust the Zoom as necessary to view the trajectory. Is your prediction verified? {Y, N, U, NOT} Can you explain the results?
{Y, N, U, NOT}

## VI. FORCES ON A MASSIVE BLOCK OF "DRY ICE" FLOATING ON GLASS†

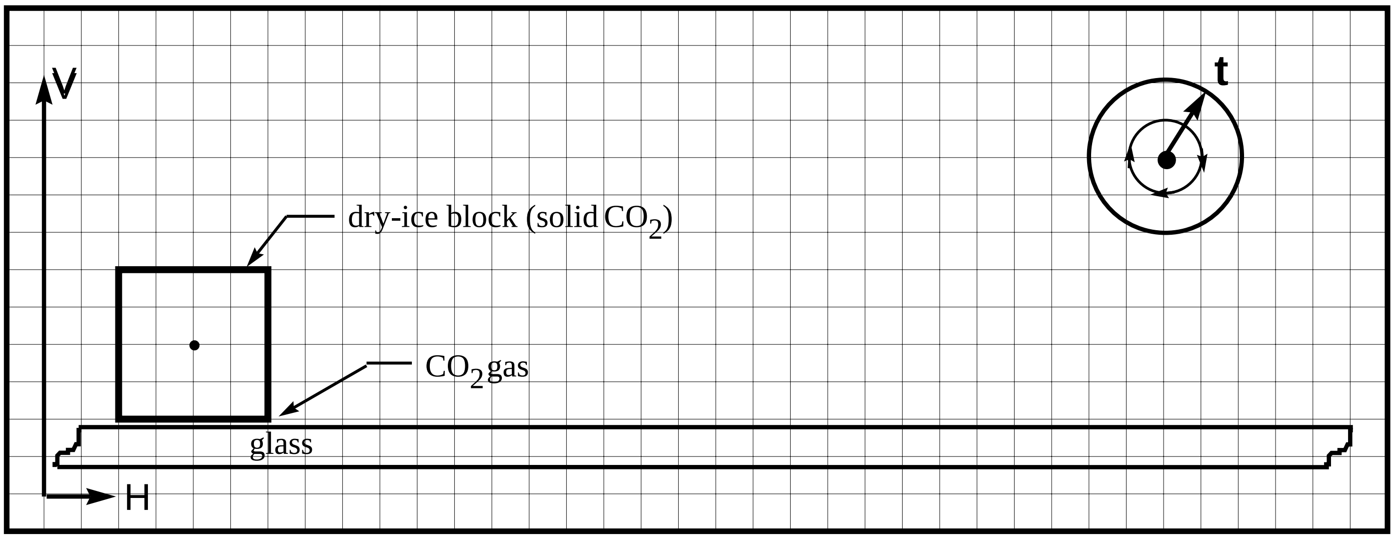
A. BLOCK "AT REST"

**Using protective gloves**, place a "dry-ice"* block weighing about 50 lb** (222 N and thus a mass of 23 kg) "at rest" on a large (≈ 42 × 72-inch) plate of glass resting on a lab table with a perimeter fence to retain the dry ice. (Easier said than done! Your block may move slowly even after your instructor has leveled the lab table by shimming the legs – but idealize and consider the block in the limit in which the glass on the table is perfectly level.)

In doing the following dry-ice experiments, it's very important to *always keep the block at one corner of the table when not in use* so that water vapor does not condense on the working surface of the glass and cause the block to freeze to the glass.

In the figure below, the separation between the glass and the block has, of course, been exaggerated.

FORCES ON A DRY-ICE BLOCK AT REST OVER GLASS




1. Is there a contact force on the block **by the *glass***? {Y, N, U, NOT} [HINT: What's ***TOUCHING*** the block? Move the block to a new resting position over the glass and quickly (before water vapor can freeze at the block-glass interface) slide a *smooth* piece of aluminum foil between the block and the glass!]

2. In the above figure show ALL the force vectors acting **on the dry-ice block**. Draw velocity vectors if they exist.

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† Adapted from A.B. Arons, *A Guide to Introductory Physics Teaching* (John Wiley, New York, 1990) p. 60 - 63.

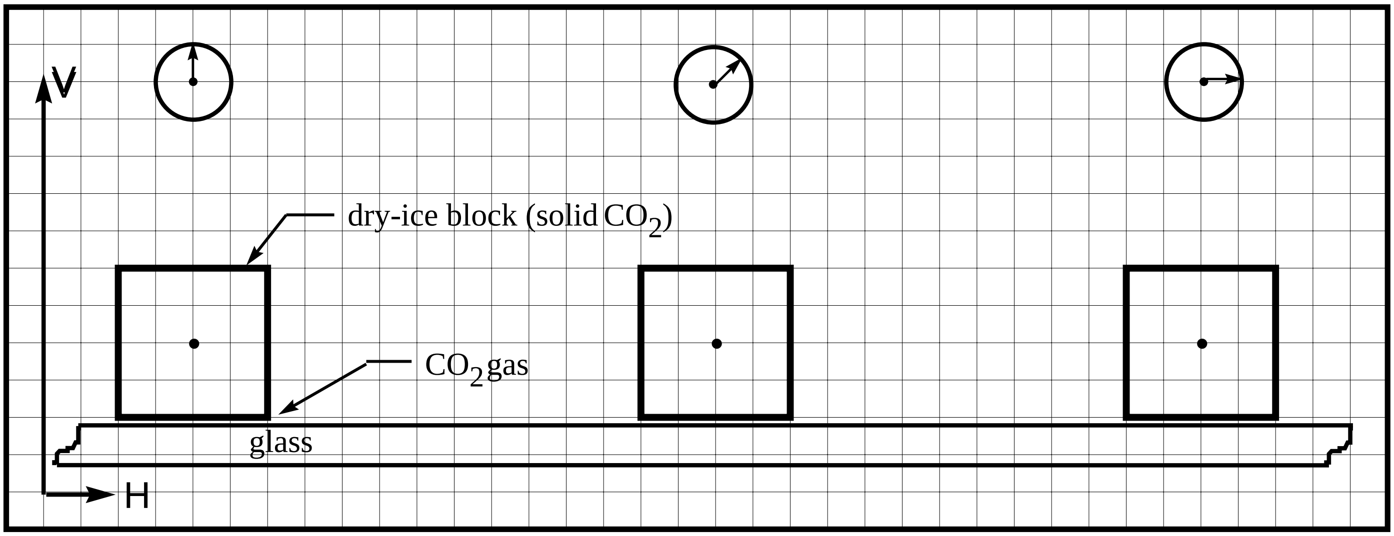
* "Dry ice" is solid carbon dioxide $CO_2$. At atmospheric pressure it is in equilibrium with its vapor at a temperature of – 79° C = –110° F. (For a good treatment see the text by Sears, Zemansky, Young, 6th ed., p. 343.)

** Our experience indicates that a large 50 lb block can be used successfully even in humid weather *if the block is kept at one corner of the table when not in use* so that water vapor does not condense on the working surface of the glass.

B. TAP A BLOCK WHICH IS INITIALLY AT REST

With the block initially at rest in the lab frame, give the block a tap (an "impulsive force," i.e., a force acting only over a very small time interval $\Delta t$) with your gloved hand in a horizontal direction such that the block slides over the glass. Sketch the block over the glass at 3 positions while *in motion **after** the block has left your hand*: near the start, middle, and end of its horizontal motion. Show all the $\vec{\mathbf{F}}$ and $\vec{\mathbf{v}}$ vectors in the snapshot sketches below.

FORCES ON AND VELOCITIES OF A BLOCK TAPPED AFTER INITIALLY BEING AT REST




1. Is the block sketched above in equilibrium in the lab frame? {Y, N, U, NOT} [HINT: Please consider the *definition* of "equilibrium" in Sec. II-F before answering this question.]

2. In the above sketch, is there a **NET** horizontal force vector on the block? {Y, N, U, NOT}

3. In the above sketch, is there a horizontal force vector on the block? {Y, N, U, NOT}

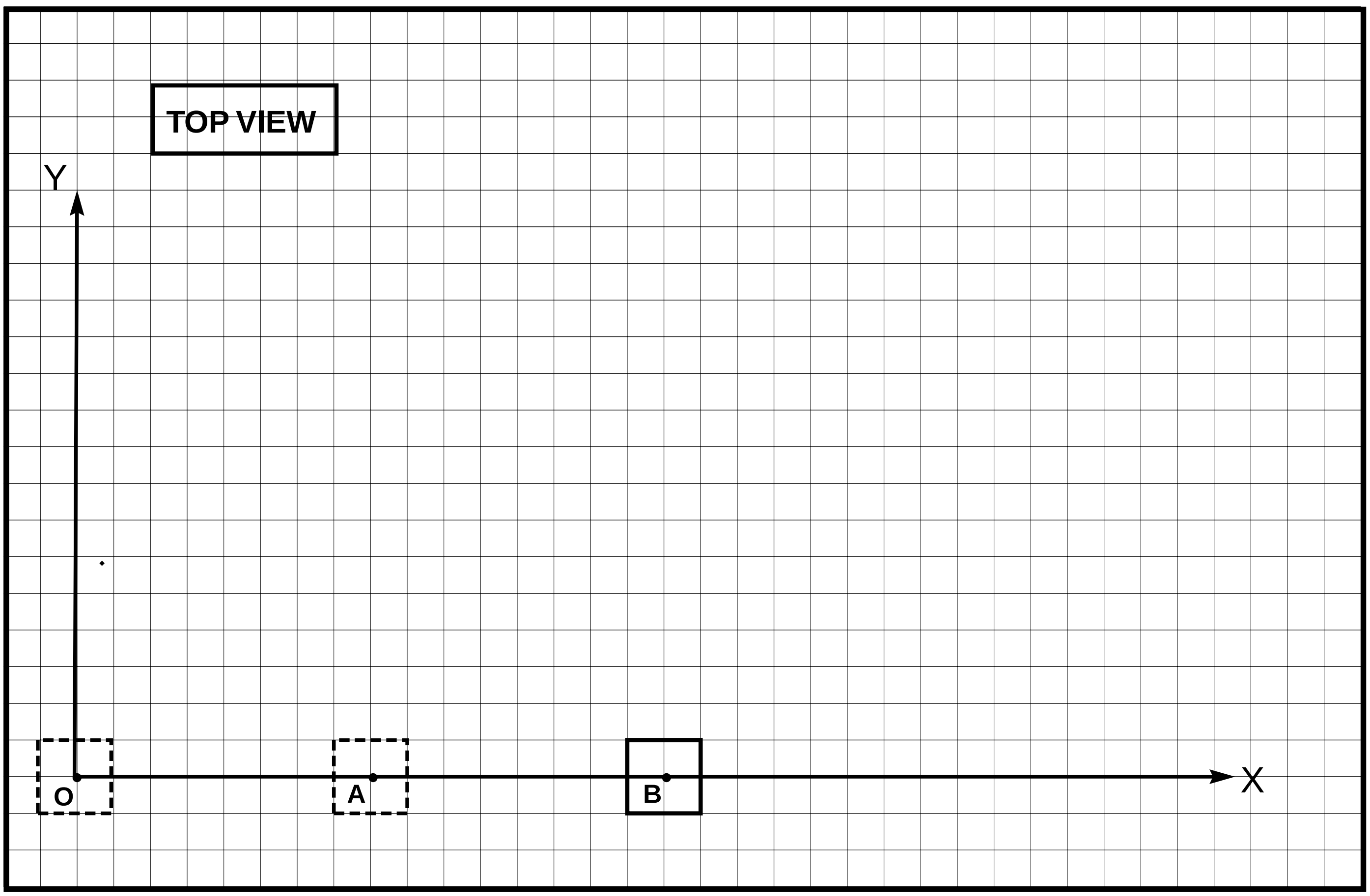
C. TAP A BLOCK WHICH IS INITIALLY MOVING

Suppose you were to give the block a tap so that it moves along a nearly straight line with a nearly constant velocity $\vec{v}$. Then suppose a partner were to give the block a brief tap (an "impulsive force," i.e., a force acting only over a very small time interval $\Delta t$) in a direction ***perpendicular*** to the original path. How would the block move?

The figure below shows a top view of the dry ice table and of the block (a) at the origin O just *after* receiving the first tap in the direction of +x, (2) at point A , halfway between O and B, (3) at point B just *after* receiving the second tap in the direction of +y. (Note that we are assuming here that the intervals $\Delta t$ over which the taps occur are so short that the movement of the block is imperceptible on the scale of the drawing.)

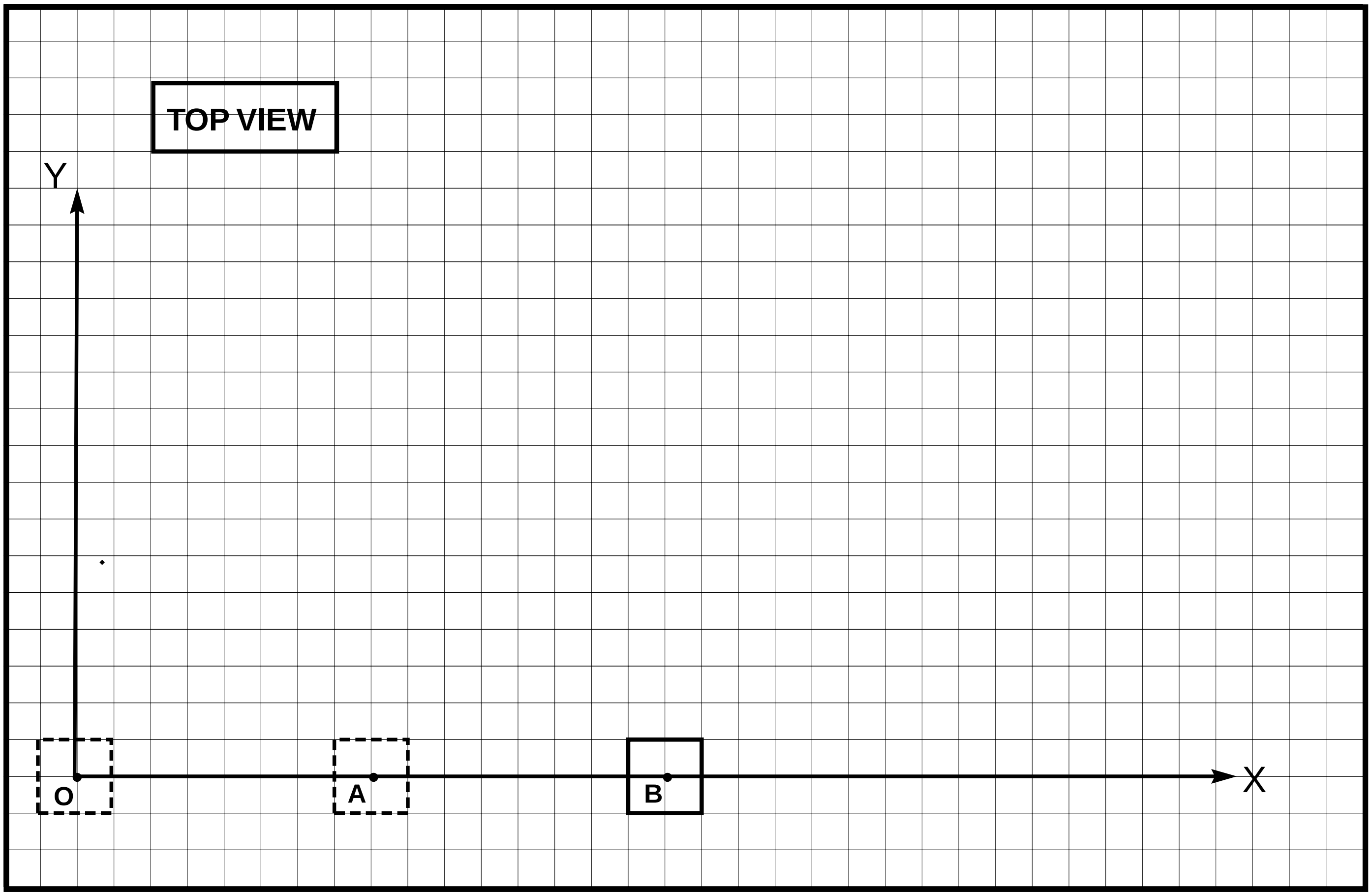
Show YOUR PREDICTION of the path of the block after the second tap. (Always represent paths as *continuous* straight or curved lines.) Draw snapshot sketches of the block in two positions after the second tap. Show the velocity vectors of the block on the 5 snapshots of the block with their tails at the center of the block.

PREDICTION OF PATH AND VELOCITY OF THE BLOCK AFTER THE TAP




1. Perform the above experiment. Do your results agree qualitatively with your predictions? {Y, N, U, NOT} If not, sketch your results on the next page.

EXPERIMENTAL RESULTS: Same drawing as above but for the observed motion.




2. Can you explain your results in terms of N1? {Y, N, U, NOT}

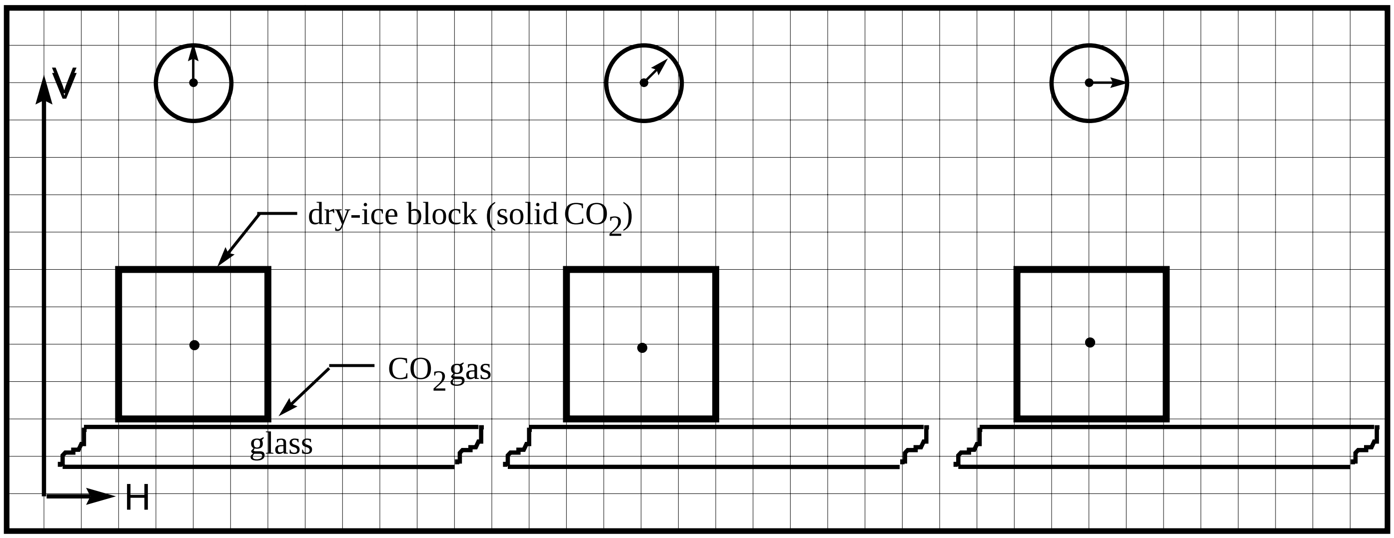
3. How do the *magnitudes* of the velocities before and after the tap compare?

4. *During* the two taps, how does the force on the block by the hand compare with the force on the hand by the block?

D. BLOCK INITIALLY MOVING AND THEN SLOWED

Suppose you were to give the block a push so that it moves along a straight line with a nearly constant velocity $\vec{\mathbf{v}}$. Can you propose a good method to *continuously and uniformly slow the block down* to nearly zero velocity? ("*Continuously and uniformly slow the block down"* means that the velocity of the block decreases continuously by equal amounts in equal intervals of time, i.e., the acceleration is constant) {Y, N, U, NOT} The snapshot sketches below show the block while *in motion* ***after*** *the initial push*: at times near the start, middle, and end of its uniformly decreasing-velocity motion. Show all the $\vec{\mathbf{F}}$ and $\vec{\mathbf{v}}$ vectors in the snapshot sketches below. Justify your above answer by indicating your method in the sketches.

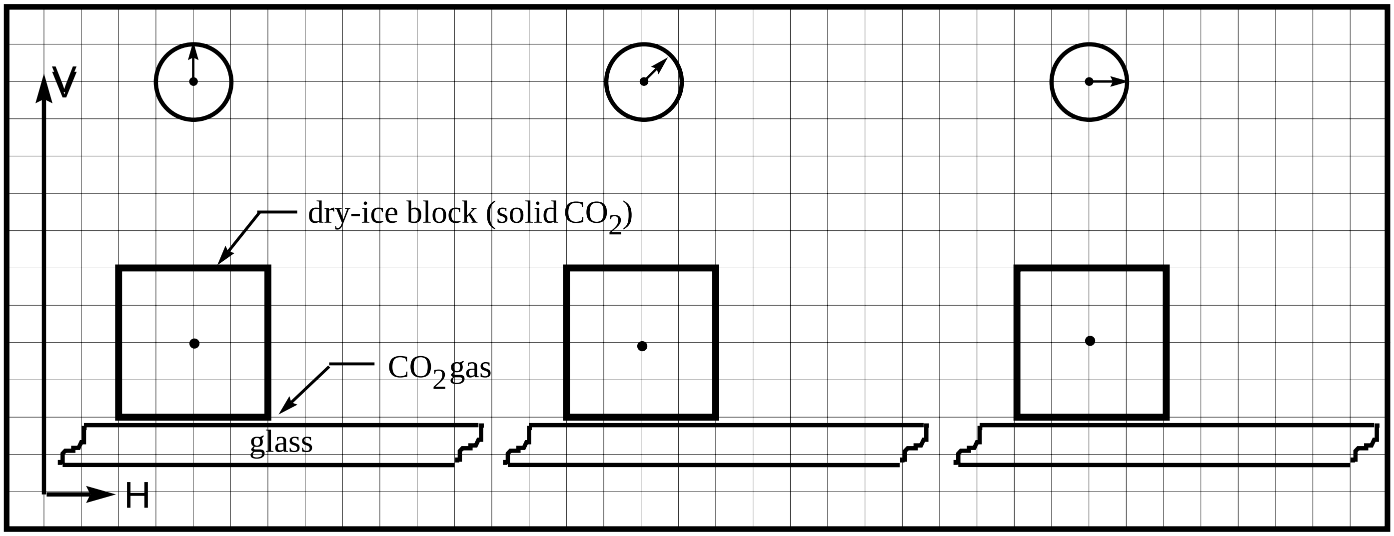
PROPOSED METHOD FOR CONTINUOUSLY AND UNIFORMLY SLOWING THE BLOCK DOWN




1. Try out your method. Does it work? (You may or may not wish to reorient the V-H axes shown in the drawing.) {Y, N, U, NOT}

2. If you didn't answer "Y" to the above question, then discover a good method experimentally and sketch the method below. Show all the $\vec{F}$ and $\vec{v}$ vectors in the snapshot sketches.

ACTUAL METHOD FOR CONTINUOUSLY AND UNIFORMLY SLOWING THE BLOCK DOWN

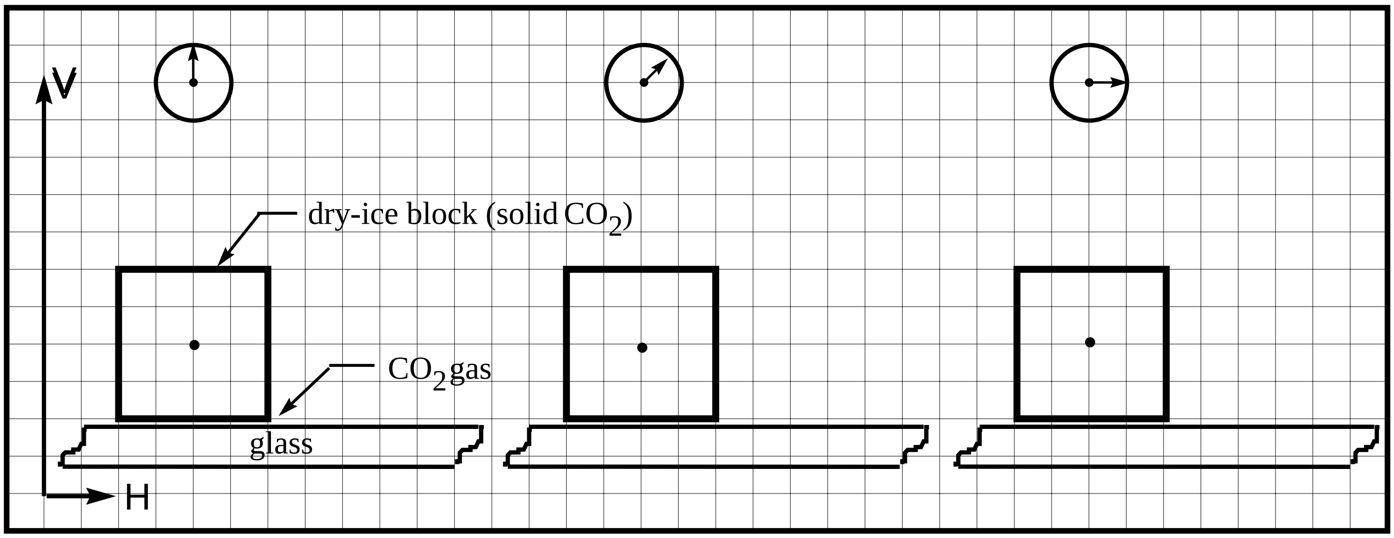



3. Explain your method in terms of N1.

E. BLOCK STATIONARY AND THEN BROUGHT TO A HIGH VELOCITY

Suppose the block is initially stationary. Can you propose a good method to *continuously and uniformly speed the block up* to some relatively high velocity? ("*Continuously and uniformly speed the block up"* means that *the* velocity of the block increases continuously by equal amounts in equal intervals of time, i.e., the acceleration is constant) {Y, N, U, NOT} (You may or may not wish to reorient the V-H axes shown in the drawing.) Show all the $\vec{\mathbf{F}}$ and $\vec{\mathbf{v}}$ vectors in the snapshot sketches below. Justify your above answer by indicating your method in the sketches.

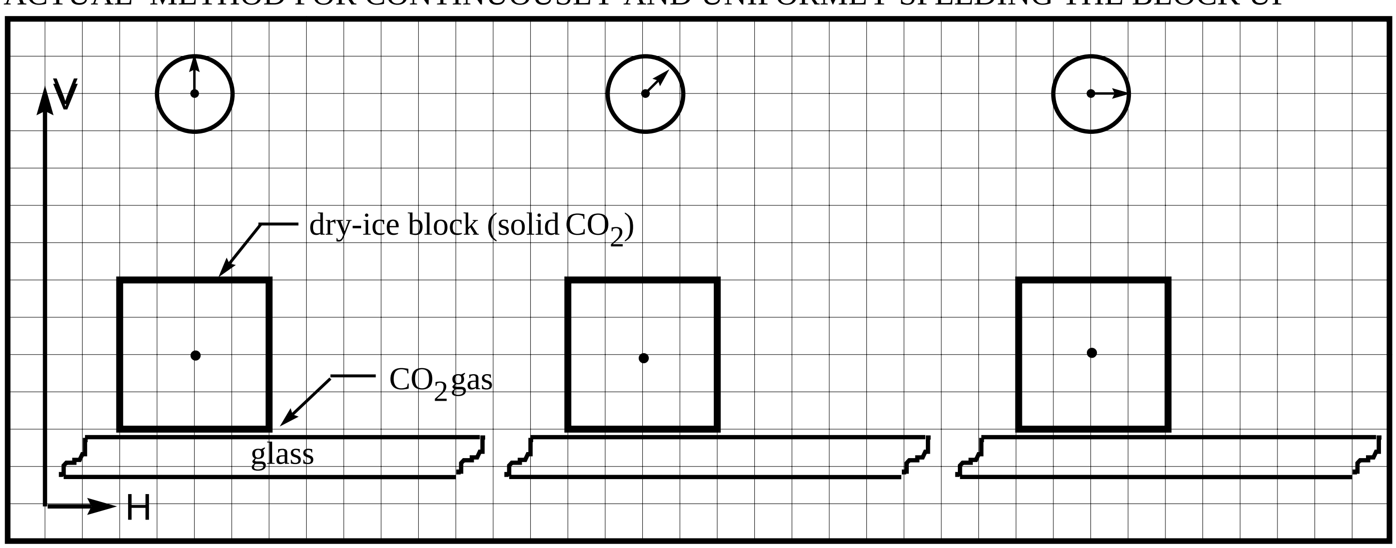
PROPOSED METHOD FOR CONTINUOUSLY AND UNIFORMLY SPEEDING THE BLOCK UP




1. Try out your method. Does it work? {Y, N, U, NOT}

2. If you didn't answer "Y" to the above question, then discover a good method experimentally and sketch the method below. Show all the $\vec{\mathbf{F}}$ and $\vec{\mathbf{v}}$ vectors in the snapshot sketches.

ACTUAL METHOD FOR CONTINUOUSLY AND UNIFORMLY SPEEDING THE BLOCK UP




3. Explain your method in terms of N1.

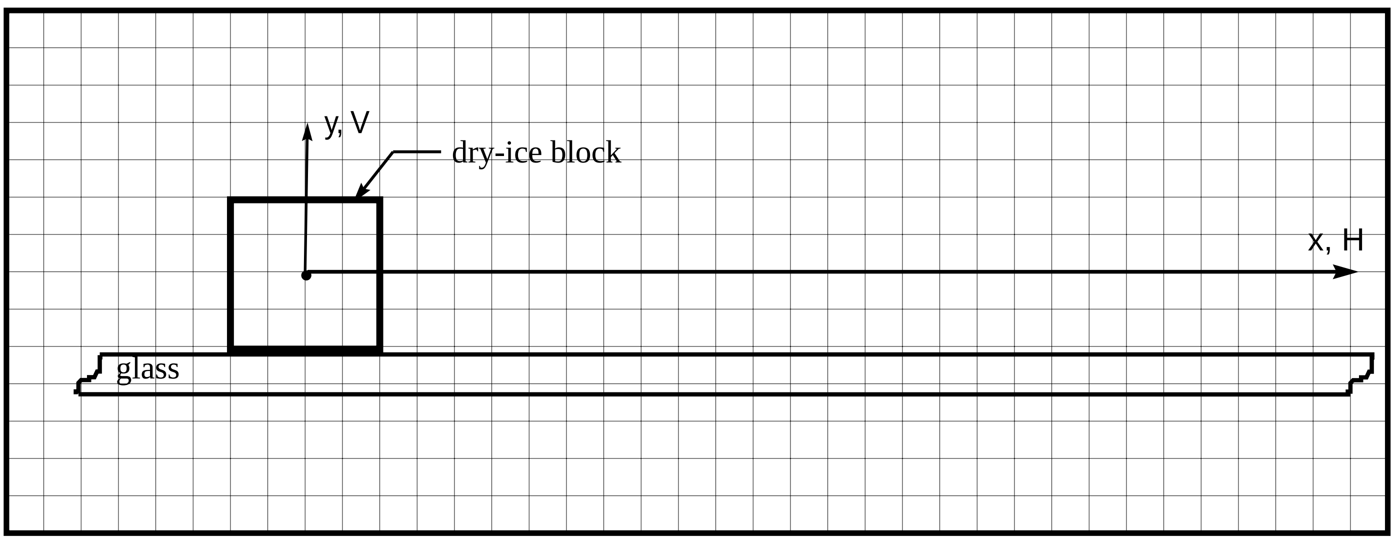
F. INCREASING THE VELOCITY OF AN INITIALLY STATIONARY BLOCK

1. Suppose that you were to hitch a flea to a dry-ice block which is initially at rest. Could the flea continuously increase the velocity of the block up to some value easily visible to the unaided eye? {Y, N, U, NOT} (Your lab instructor will take bets.)

a. In considering this problem would you be justified in ignoring the small frictional force $\vec{\mathbf{f}}_{\text{on block by gas}}$? {Y, N, U, NOT}. [HINT: Pretend you are a flea trying to accelerate a dry ice block. Would the frictional force be of any concern to you? {Y, N, U, NOT}]

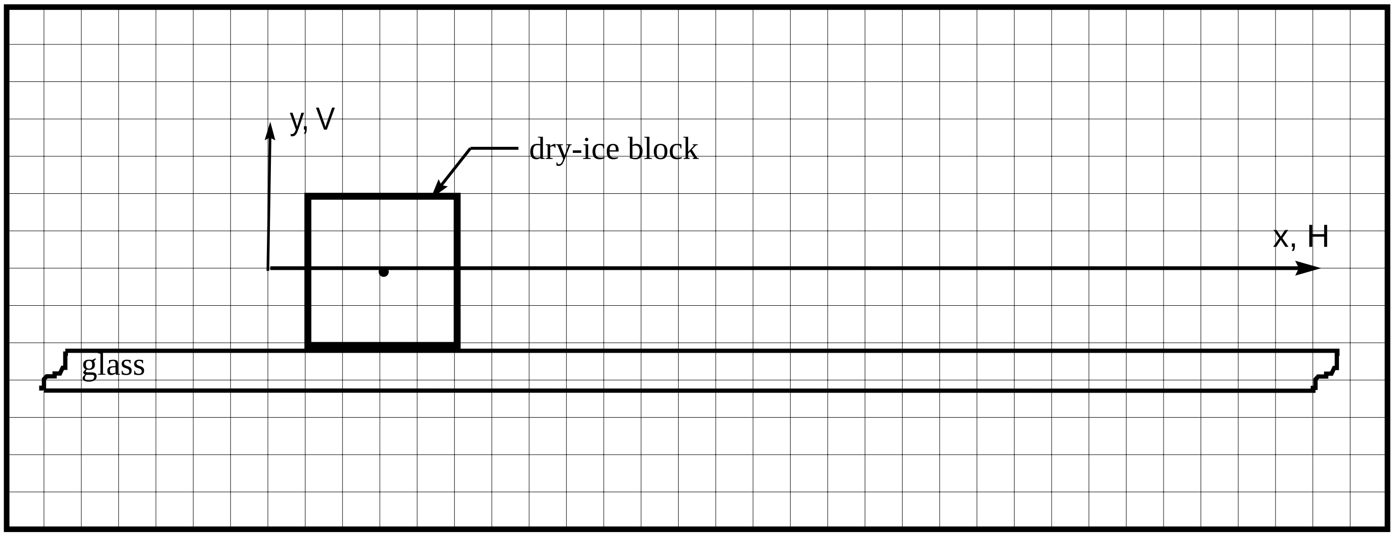
b. Assume the block is initially at rest. Can you figure out what physical parameters would determine whether or not the flea could accelerate the block? {Y, N, U, NOT}
HINT #1: Sketch a thought experiment in which the flea is *on the verge* of accelerating the block.
HINT #2: Ignore $m_{\text{harness}}$, since $m_{\text{harness}} << m_{\text{block}}$. Then the force $F_{\text{on harness by flea}}$ is just equal to the tension T in the harness and $F_{\text{on block by harness}} = T = F_{\text{on harness by flea}}$.

FLEA IS ON THE VERGE OF ACCELERATING THE BLOCK



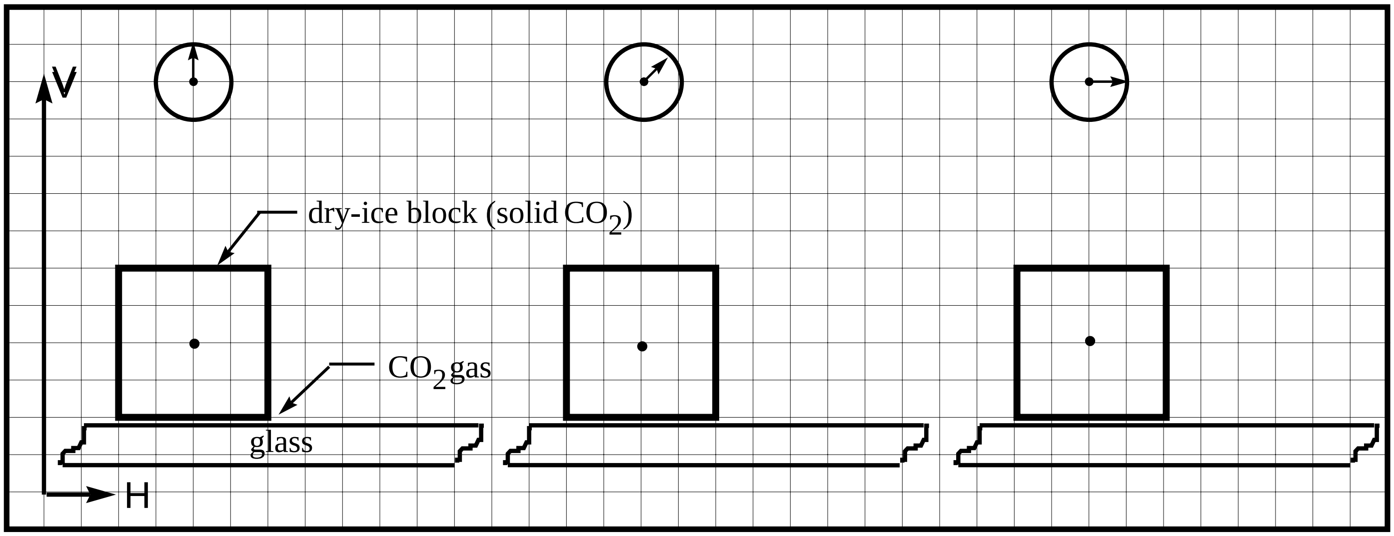
c. Suppose the flea were able to move the block with a constant acceleration $\vec{a}$ starting at a time t = 0. Can you figure out what physical parameters would determine the velocity $\vec{v}$ of the dry-ice block at some given time $\tau$ during the constant $\vec{a}$ motion? {Y, N, U, NOT}
HINT #1: Sketch a thought experiment in which the flea *is* accelerating the block.

FLEA *IS* ACCELERATING THE BLOCK




3. Try the above experiment and use force-motion-vector snapshot sketches to indicate the results in the space on the next page. Show the harness and the flea. Do your results agree with your prediction? {Y, N, U, NOT} (If you can't find a flea or have trouble making a harness, then conduct and sketch a "thought experiment.")

**CHECK ONE:**
A FLEA (DOES___ , DOES NOT____ACCELERATE AN INITIALLY STATIONARY DRY-ICE BLOCK




G. BLOCK MOVED ALONG A CURVED PATH AND THEN RELEASED

1. Do you think you can hold the block and move it **along a curved path** so that when you release the block *it will continue to move along a curved path*? {Y, N, U, NOT}

2. In the space on the next page draw a TOP VIEW of the table. Sketch the *curved path* of the block before the release, the release point P, and your prediction of the path after the release. Show the block at several points along the path. Show the velocity vectors which describe the motion of the block. [HINT: One approach is to place your gloved hand on the top of the block and let your arm pivot about your shoulder so as to move the block in a nearly circular arc. Then suddenly remove your hand from the block.]

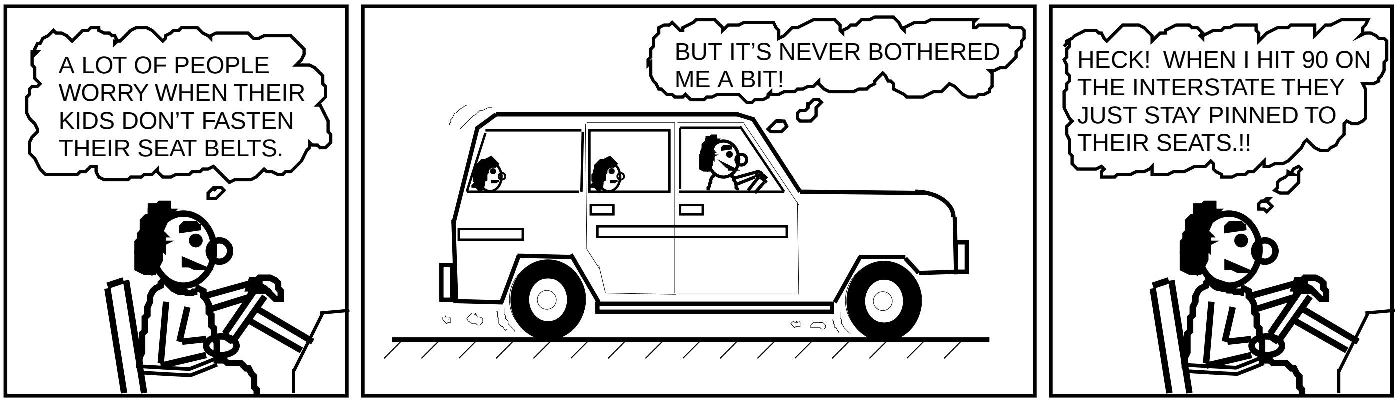
PREDICTION:  BLOCK MOVED ALONG A CURVED PATH AND THEN RELEASED.

3.  Try the above experiment.   Do the results agree with your prediction?  {Y, N, U, NOT} Sketch your results below *if* they do not agree with your prediction.

EXPERIMENTAL RESULTS:  BLOCK MOVED ALONG A CURVED PATH AND THEN RELEASED.

4.  Explain your results in terms of N1.

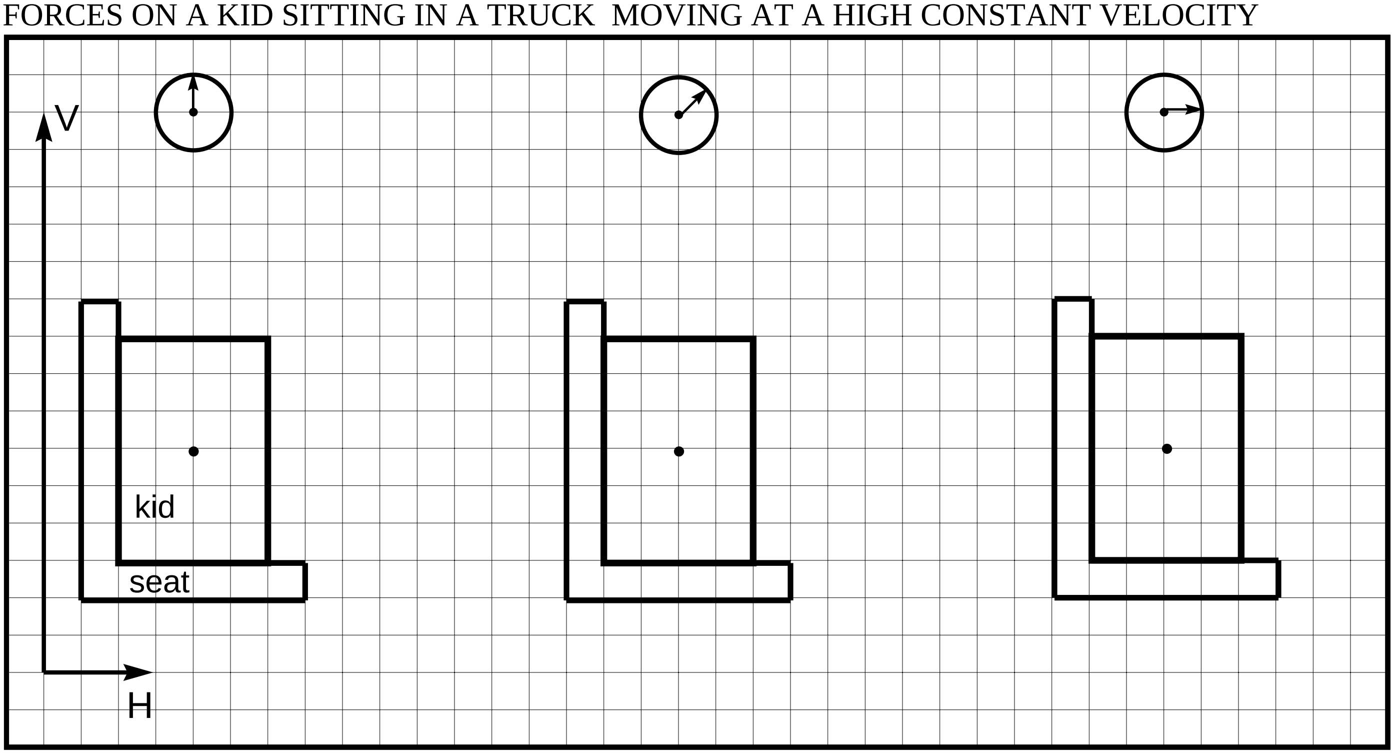
## VII. FORCES ON A KID IN TRUCK




1. Can a truck driver pin kids to their seats by driving his truck at very high *constant* velocity $\vec{v}$ as suggested in the cartoon above? {Y, N, U, NOT} [HINT: It may help to consider your earlier experience, Sec. III-D, in carrying a disk across a room at constant speed in a straight line.]

2. The schematic diagram below shows a kid in her seat in a truck. Three successive positions of the kid and seat are shown in the Earth's frame of reference, as the truck moves forward at very high *constant* horizontal velocity $\vec{v}$. Draw **ALL** the force vectors acting on the kid at these 3 positions. Show the velocity vectors in the 3 positions if they exist.

FORCES ON A KID SITTING IN A TRUCK MOVING AT A HIGH CONSTANT VELOCITY



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*** $\vec{\mathbf{v}}$ ***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 it possible that a horizontal force vector could act on the kid? {Y, N, U, NOT}

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

## VIII. IDEALIZED MODELS

As mentioned in the Introduction, Sec. I-E, the idealized model of motion employed in this lab includes many simplifications and approximations. Nevertheless, calculations based on this model usually agree with experiment to within several percent. List below all the model simplifications and/or approximations used in this lab that occur to you.

ACKNOWLEDGEMENTS: This lab has benefited from (a) helpful comments of Professors Fred Lurie and James Sowinski who served as SDI lab instructors during the Spring semesters of 1993-94, (b) valuable suggestions by Laboratory Coordinator Ray Wakeland, (c) feedback from the experiments, writing, discussion, drawing, and dialogue of (1) the 1263 Indiana University introductory-physics-course students who have taken SDI labs as a major part of their regular lab instruction, (2) the 22 student volunteers from P201 classes who consented to be videotaped while working through SDI labs on Saturday mornings in the Fall of 1993-94.

## APPENDIX A: DRAWING ACCELERATION VECTORS IN TIME-SEQUENTIAL SNAPSHOT SKETCHES

A. HOW TO DRAW ACCELERATION VECTORS

Suppose one has recorded her/his qualitative observations of the motion of a block along a table top by making 3 *snapshot sketches* of the block at three sequential instants of time $t_1$, $t_2$, $t_3$ . Suppose the motion was initiated by a tap (impulsive force) from the hand in a horizontal direction as was done in Sec. IV-C ("Block Sliding to Rest").

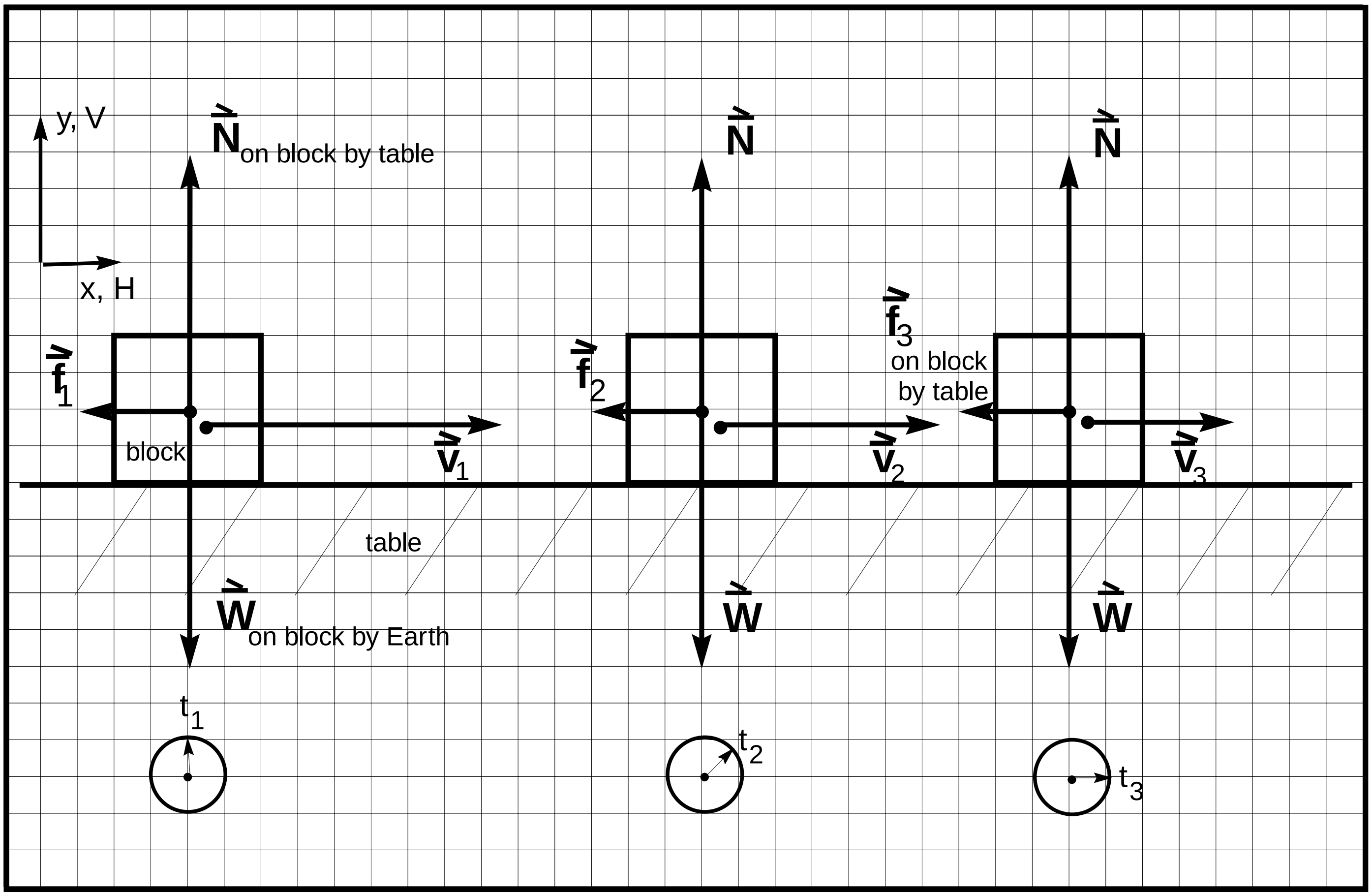



Fig. 1. Snapshot sketches at three sequential instants of time ($t_1$, $t_2$, $t_3$) show a wooden block sliding to rest on a table as observed in Sec. IV-C.

The *qualitative* observations in Sec.IV-C of the block sliding to rest on the table as recorded in Fig. 1 showed only that *as time increased the velocity decreased*:

$$v_1 (t_1) > v_2 (t_2) > v_3 (t_3), \qquad \text{......} \quad (1)$$

and that as far as we could tell:

the motion was *continuous.* ..........(2)

Let's *assume*, consistent with our observations, Eq. (1, 2), the existence of a *constant* NET horizontal force (just the frictional force **f)** as depicted in Fig 1 :

$$\vec{\mathbf{f}}_1(t_1) = \vec{\mathbf{f}}_2(t_2) = \vec{\mathbf{f}}_3(t_3) \neq 0. \quad ......................................................... (3)$$

Let's also *assume* the validity of Newton's second law:

$$\vec{\mathbf{F}}_{\text{net on body}} = m_{\text{body}}\, \vec{\mathbf{a}}_{\text{body}}. \quad ......................................................... (4)$$

From *only* the lab observations [Fig. 1 and Eq. (1 - 4)], can we *infer* [i.e., can we conclude ***only*** from Fig. 1 and Eq. (1 - 4)] :

a. that the accelerations $\vec{\mathbf{a}}_1$, $\vec{\mathbf{a}}_2$, $\vec{\mathbf{a}}_3$ are non-zero? {Y, N, U, NOT}*

b. the *directions* (signs in the 1-D case) of the acceleration vectors $\vec{\mathbf{a}}_1$, $\vec{\mathbf{a}}_2$, $\vec{\mathbf{a}}_3$?
{Y, N, U, NOT}

c. the *relative magnitudes* of the acceleration vectors $\vec{\mathbf{a}}_1$, $\vec{\mathbf{a}}_2$, $\vec{\mathbf{a}}_3$ ? {Y, N, U, NOT}

---

*Here and throughout this lab, please recall the and abide by the ground rules for SDI labs set forth in the introduction and recall that a curly bracket {.......} indicates that you should **ENCIRCLE** O a response within the bracket and then, we **INSIST**, briefly **EXPLAIN** or **JUSTIFY** your answers in the space provided on these sheets. The letters {Y, N, U, NOT} stand for {Yes, No, Uncertain, None Of These}.

d. the *lengths* of the vectors representing $\vec{\mathbf{a}}_1$, $\vec{\mathbf{a}}_2$, $\vec{\mathbf{a}}_3$ relative to the *lengths* of the vectors representing $\vec{\mathbf{f}}_1$, $\vec{\mathbf{f}}_2$, $\vec{\mathbf{f}}_3$ ? {Y, N, U, NOT}

e. the *lengths* of the vectors representing $\vec{\mathbf{a}}_1$, $\vec{\mathbf{a}}_2$, $\vec{\mathbf{a}}_3$ relative to the *lengths* of the vectors representing $\vec{\mathbf{v}}_1$, $\vec{\mathbf{v}}_2$, $\vec{\mathbf{v}}_3$ ? {Y, N, U, NOT}

2. In Fig. 1 above, draw in the acceleration vectors $\vec{\mathbf{a}}_1$, $\vec{\mathbf{a}}_2$, $\vec{\mathbf{a}}_3$, if they exist.

B. DRAW ACCELERATION VECTORS IN SDI LAB #1 SKETCHES

Examine your sketches in SDI Lab #1, "Newton's First and Third Laws." From the record of your Lab #1 observations [of the nature of Fig. 1 and Eq. (1) above] and assumptions [of the nature of Eq. (2 - 4) above] **DRAW IN THE ACCELERATION VECTORS** where you think they exist.

IF YOU HAVE NOT YET CONFERRED ON "D" (DISCUSS)-MARKED SECTIONS OF SDI LAB #1 WITH YOUR INSTRUCTOR, THEN DISCUSS THOSE SECTIONS WITH HER/HIM. AFTER REVISING AND/OR COMPLETING THESE SECTIONS, DRAW IN THE ACCELERATION VECTORS.

## APPENDIX B: FORCES ON MAGNETS

A. HOLD TWO MAGNETS.

Hold two permanent magnets, one in each hand and as far apart as possible. Slowly bring the two magnets together. Play around so as to determine magnet orientations for *maximum attraction* and magnet positions so close (a millimeter or so) that you can barely keep them from touching.

In order to understand the physics of this situation, it is essential that you draw a LARGE LABELED DIAGRAM. In the space below draw a "FRONT VIEW" ( i.e., the view of an observer whose line of sight is horizontal) of **both** magnets [labeled "#1"(solid lines) and " #2"(dashed lines)] in this maximum attraction position. For simplicity *orient the magnets so that the magnetic force* (call it $\vec{\mathbf{M}}$**)** *between them is horizontal.* Draw the fingers of the hand holding magnet #1.

According to N1 and N2, the motion of magnet #1 *depends on **ALL** the forces acting **ONLY** on magnet #1*. Therefore, show **ALL** the force vectors acting ***ONLY*** **on this magnet #1** (*don't forget the subscript designation "**on** #1 **by**________"*).

Hint #1: To assist your concentration in applying N1 to magnet #1, *color ONLY that body yellow*.

Hint #2: Don't forget the reference axis V-H!

Hint #3: It's useful to *consider separately the **vertical** and **horizontal** components of the forces.*

Hint #4: Although your fingers may pinch the magnet with relatively large opposing forces, it's simplest to only show the *unbalanced* forces $\vec{\mathbf{F}}_{\text{net vertical on magnet \#1 by hand}}$ (call this simply $\vec{\mathbf{N}}_{\text{on \#1 by hand}}$) and $\vec{\mathbf{F}}_{\text{net horizontal on magnet \#1 by hand}}$ (call this simply $\vec{\mathbf{f}}_{\text{on \#1 by hand}}$) .

FORCES ON MAGNET #1 HELD VERY CLOSE TO ATTRACTING MAGNET #2

1. Is magnet #1 in equilibrium in the lab frame? {Y, N, U, NOT} [HINT: Please consider the *definition* of "equilibrium" in Sec. II-F before answering this question: ***a body is in equilibrium in a given reference frame if and only if its vector velocity*** $\vec{\mathbf{v}}$ ***as observed in that reference frame is constant in time.***]

2. What body or bodies are **TOUCHING** magnet #1? (**Study your diagram !!**) (*Only these can exert **contact** forces!!*).

3. Are there any force vectors shown in your drawing which are due to interaction with bodies which DO **NOT** TOUCH magnet #1? (**Study your diagram!!**) {Y, N, U, NOT}

4. Are the *relative* force-vector magnitudes (as shown by the *relative* lengths of the vector arrows) in your sketch above consistent with Newton's first law (NI)? {Y, N, U, NOT} [HINT #1: Study the Newton's First Law diagram hanging above your table (also at the back of this manual). HINT #2: ***Consider N1 first along the vertical axis and then along the horizontal axis.***]

5. Are there any "magnetic" forces acting on magnet #1? {Y, N, U, NOT} If so, indicate them in an $\vec{\mathbf{F}}_{\text{on A by B}}$ manner:

6. Are there any "gravitational" forces acting on magnet #1? {Y, N, U, NOT} If so, indicate them in an $\vec{\mathbf{F}}_{\text{on A by B}}$ manner:

7. If you answered "No" to *both* "5" and "6," or "No" to one of "5" and "6," please explain your reasoning. If you answered "Yes" to *both* "5" and "6," should the lengths of the vectors in "5" and "6" be about the same? {Y, N, U, NOT} Can you think of an experimental method which would roughly indicate the relative magnitudes of the magnetic and gravitational forces acting on magnet #1? {Y, N, U, NOT}

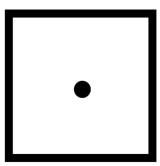
8. In this experiment, what are the forces which are *directly felt* by your hand? (Indicate them as $\vec{\mathbf{F}}_{\text{on A by B}}$.)

9. *Considering your answers to questions 1 - 8 above*, do you think that non-touching (i.e., "non-contact," "action-at-a-distance," or "field" ) forces actually exist? {Y, N, U, NOT}

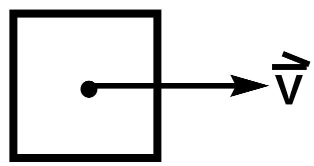
# NEWTON'S FIRST LAW

**CAUTION :** VALID ONLY IN AN
INERTIAL REFERENCE FRAME (IRF)!

**N1 (The "Law of Inertia"):**
**EVERY BODY CONTINUES IN ITS STATE OF REST, OR OF UNIFORM MOTION IN A STRAIGHT LINE UNLESS IT IS COMPELLED TO CHANGE THAT STATE BY A *NET* FORCE ACTING UPON IT.** **.......(N1)**



**OR**




$\vec{\mathbf{v}}_{body} = 0$ $\qquad$ $\vec{\mathbf{v}}_{body} = \text{constant}$

UNLESS $\vec{\mathbf{F}}_{\text{net on body}} \neq 0$

"**EQUILIBRIUM**" ≡ [ $\vec{\mathbf{v}}_{body} = \text{constant}$ (in magnitude and direction) ]

Note that the **constant** can be zero (body at rest)
or some finite value (body moving)

N1 can be phrased as:

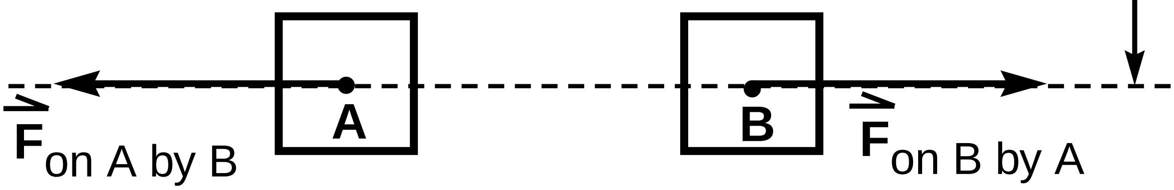
$$[\ \vec{\mathbf{v}}_{body} = \text{constant}\ ] \quad \text{implies} \quad \vec{\mathbf{F}}_{\text{net on body}} = 0$$ **......................(N1)**

**OR**

If a body is in "**EQUILIBRIUM**" then $\vec{\mathbf{F}}_{\text{net on body}} = 0$ **................(N1)**

# NEWTON’S THIRD LAW

**N3 (Modern Version):**
**WHENEVER ONE BODY EXERTS A FORCE ON ANOTHER, THE SECOND ALWAYS EXERTS A FORCE ON THE FIRST THAT IS EQUAL IN MAGNITUDE, IS OPPOSITE IN DIRECTION, AND HAS THE SAME LINE OF ACTION** **...(N3)**




N3 can be phrased as:

$$\vec{F}_{\text{on A by B}} = -\vec{F}_{\text{on B by A}}$$ **.......................................(N3′)**

The "AB – SWITCH " will ALWAYS give the N3 Action-Reaction Pair!!

The Action-Reaction Forces ARE NEVER ON THE SAME BODY!!