87-88

Chapter 2 NEWTON'S LAWS OF MOTION

In previous chapters we learned to describe the motion of a body in terms of its displacement, velocity and acceleration without regard for what caused the motion in the first place. Such a descriptive study of motion which ignores its causes is called KINEMATICS . In this chapter we will attempt to account for and describe the causes of motion, and in doing so will be engaged in a study of DYNAMICS.

As you probably already know, forces are the cause of motion. Newton's law of motion puts this in quantitative terms of stating that the vector acceleration of a body is directly proportional to the net vector force exerted on a body. This chapter will further acquaint you with Newton's law - its origin, its verification, and above all, its applications.

PERFORMANCE OBJECTIVES

Upon completion of this chapter, you should:

1. be able to contrast between those before Galileo who developed understanding about their world through "common sense" observations with those of Galileo and those who followed who developed understanding through experimentation and logical reasoning.

2. be able to develop an appreciation for the conflicts that existed between Galileo's scientific thinking and the church's authority.

3. be able to recognize if no unbalanced force acts on an object, that object will continue in it's present state of rest or uniform motion.

4. be able to recognize that when an unbalanced force does act on an object, the object is accelerated in the direction of the force.

5. be able to illustrate the direct relationship between the unbalanced force applied to an object and the acceleration it experiences.

6. be able to state what is meant by the terms inertial mass and gravitational mass.

7. be able to define the Newton as the unit of force.

8. given any two of acceleration, mass, or unbalanced force, deduce the third variable using the relationship: $F = m\ a$.

18. Fill in the table.

	LENGTH	MASS	TIME	FORCE (WEIGHT)
Metric (MKS)	__________	__________	_______	______________
Metric (cgs)	__________	__________	_______	______________
English (FPS)	__________	__________	_______	______________

a. How many dynes in a Newton? Slug = ___________________(units)

b. See blue sheet for answers. See instructor for an explanation.

19. Problems:

page 37:	#18	#19	
page 39:	#25	#27	#28
page 38:	#20	#21	
page 39:	#30	#31	

20. Einstein said that the mass (m) of any object depends on the velocity (v) that it is traveling and its mass (at rest) (m_o) according to:

$$m = \frac{m_o}{\sqrt{1 - v^2/c^2}}$$ (where $c = 3 \times 10^8$ m/sec) (speed of light)

a. How would this affect Newton's Law, F = ma?

b. What is the value of 'm' when v = 30 m/sec? (about 60 mi/hr)

c. What is the value of 'm' when v = 1/2 c?

21. Complete the enclosed written exercise. Have it evaluated by your instructor.

Thought for the chapter: 92 - 61 - 92 ! And yours?

Answers Chapter 2

5. (a) 14.1 cm/flash or 33.7 cm/sec (b) 6.5 (c) 15.5 cm

[illegible]. (1) no
(2) ball rolls forever
(3) S.A.B.
(4) v = 20 cm/sec
(5) S.A.B.
(6) (a) 5.3 cm stays the same (b) S.A.B.
(7) 8 99.6 21.0 50 6 14
(8) to right

10. 9.8 Newtons (a)[2] 4.9 N plus 1/2 weight of bar for each
(a)[3] Bottom: 9.8 N Top: 9.8 N plus weight of bottom balance

12. (a) no (b) Everything will accelerate to the left unless the feet of horse 'J' snags on the ground. Then and only then will the rope break.

13. (9) 30 cm/sec/sec
(19) (a) 1.5 (b) 0.9 m/s
(23) S.A.B.

15. (16) Definitions differ because they arise from 2 different situations.
(12) 1.5 m/sec/sec
(14) (a) same (b) a = 2/3 a (in Fig 2-9)
(15) 3
(17) 4 m/sec/sec

17. (a) see Study Notes (b) Newton = kg-m/sec/sec (e) 4.46

18.

Meter	Kilogram	Second	(Newton)
centimeter	gram	second	(dyne)
Foot	(Slug)	Second	Pound

(a) 1×10^5 pound sec^2/ft

19. (18) 5 Newtons
(19) 30 Newtons
(25) 6 m/sec/sec
(27) S.A.B.
(28) (a) 1 sec (b) 12 m/sec
(20) 7.5 m/sec
(21) 3.8 m/sec
(30) (a) 1/6 m/sec/sec (b) 1/4 m/sec/sec (c) 2.3 Newton
(31) S.A.B.

20. (b) $m = m_o$ (c) $m = 1.15\ m_o$

The History of Science Before Galileo

Before the scientific revolution of the 16th and 17th centuries, the accepted authority on the laws of nature was Aristotle, whose views were endorsed by the Catholic Church. Perhaps most important among these was the picture of the universe as a stationary earth encircled by eight revolving spheres. To this scheme, Ptolemy had added an invisible ninth sphere.

With the Renaissance, Aristotelian ideas began to be questioned. Renaissance philosophy, the Protestant Reformation, rediscovery of Greek texts contradicting Aristotle, and geographical discoveries shook the roots of Catholic faith, encouraged observation of nature, and prodded scientific investigation in many fields.

In 1543, Nicholas Copernicus proposed the revolutionary theory that the sun, not the earth, was the center of the universe. Shortly the Church denounced the new view as heresy, retaining Aristotle as sole source of scientific truth.

Galileo's "Dialogue on the Great World Systems", published in 1632, was presented as an inconclusive debate between Aristotelian-Ptolemaic and Copernican theories. His emphasis, though, left no doubt of his support for Copernicus. Under pressure from the Inquisition, Galileo publicly denied his own observations. Afterwards, however, he secretly wrote and published another very influential scientific text, "Dialogues Concerning Two New Sciences", which pertain to dynamics and statistics.

1. Film: GALILEO: THE CHALLENGE OF REASON (30 min)

   It was Galileo who is credited as the father of science as we know it today. The previous Aristotelian scheme was essentially qualitative and non-experimental. The scheme was based on "common sense" which we all have, even today. Galileo's experiments led him to ideas that were different than the establishment. Specifically his experiments led him to support Copernicus' view that the sun is the center of the universe. For these beliefs, Galileo was brought before the Inquisition. After showing Galileo's experiments, the film dramatizes the conflict between Galileo's new scientific thinking and the church's authority. Pay close attention to his arguments and to those of the establishment. Note the role of the bystanders (who have an open mind). Although in the end, Galileo recants, it is his view which is to dominate the scientific community since then. Note the article to the left taken from the 23 October 1980 Plain Dealer. Could it be that Galileo will someday be cleared by those who wrongly accused him?

2. Film: INERTIA (26 min) (Film Notes provided.)

3. Experiment: CHANGES IN VELOCITY WITH A CONSTANT FORCE (Notes provided.)

   a. A complete write-up is due.

   b. When you present the report for evaluation, be ready to suggest a short-cut method for determining the acceleration. It is essential that this is done before you perform the next experiment.

1. Was it necessary for Galileo to measure time in order to get the extrapolation which led him to the law of inertia?
2. If you roll a putty ball around the inside of a bowl, it soon comes to rest in the center. A steel ball will orbit quite a few times before coming to rest in the center. What would be the "ideal" motion of a ball in a bowl?
3. Why is it particularly dangerous to drive on an icy highway?
4. If a ball is rolling with a velocity of 20 cm/s and no force acts on it, what will be its velocity after 5 s?

Figure A

5. Figure A shows a portion of a tape made in an experiment in which a laboratory cart is pulled by a stretched rubber band. What can you tell about the force acting on the cart?
6. (a) Measure the extension of the spring loop in the last six images of the loop in Fig. 2–9. Is the loop extended the same amount throughout the run?
   (b) Why is the answer to this question important in the analysis of the experiment described in the text?
7. What would have been the data in Table 1 for interval 8 if it had been included?
8. Suppose the photograph in Fig. 2–9 represented a body moving from right to left. In which direction would the force be acting in this case?

Table 1 Data from Experiment Shown in Fig. 2-9

INTERVAL	x (cm)	Δx (cm)	$\Delta x/\Delta t$ (cm/s)	Δv (cm/s)	$\Delta v/\Delta t$ (cm/s^2)
1	4.1	4.1	10		
2	10.4	6.3	15	5	12
3	19.2	8.8	21	6	14
4	30.4	11.2	27	6	14
5	44.0	13.6	32	5	14
6	60.1	16.1	38	6	14
7	78.6	18.5	44	6	14

The zero on the position scale was placed at the location of the puck at the instant of the first flash. The value of x is the position of the puck at the end of the given interval.

CHAPTER 2 STUDY GUIDE -2-

4. Read: Section 2-1 Ideas About Force and Motion page 25
   2-2 Motion Without Force page 27
   2-3 Changes in Velocity When A Constant Force Acts p-31

5. Using Figure 2-5, page 29 find:

   a. the speed of the puck.

   b. the factor by which the picture was reduced.

   c. the diameter of the puck.

6. Problems: page 30: #1 #2 #3 #4
   page 32: #5 #6 #7 #8

7. You push a dry ice puck and it moves off in a horizontal direction at a constant speed.

   a. Describe the force(s) acting on the puck during the above demo.

   The puck now goes over the edge of the table and falls toward the floor.

   b. Describe the path of the puck.

   c. What forces act on the puck while in mid-air?

8. Experiment THE DEPENDENCE OF ACCELERATION ON FORCE AND MASS

   a. Written procedure is enclosed in this packet.

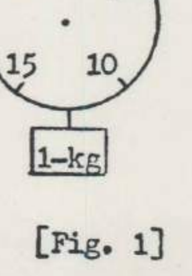
   b. A complete write-up is expected.

9. Read: Sec 2-4 Dependence of Acceleration on Magnitude of Force p-32

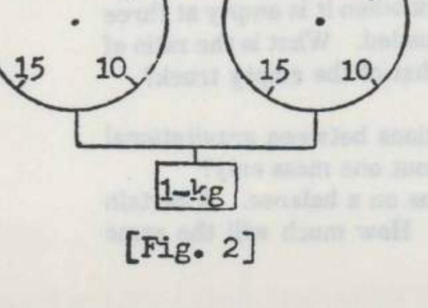
10. Perform the demonstration in Figure 1 below. Record the reading on the diagram by drawing the pointer in the appropriate direction. The:

    a. Predict the reading you will get when you perform the demonstration in Figure 2. In Figure 3.

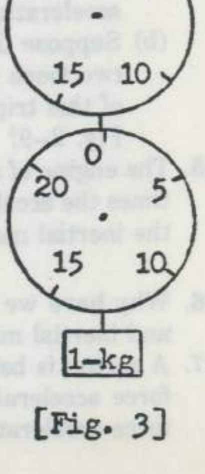
    b. Check your prediction by performing the demonstrations.



[Fig. 1]



[Fig. 2]



[Fig. 3]

9. A body is pulled across a smooth horizontal surface by a spring loop that is kept stretched by a constant amount. It is found that the body is accelerated at 15 cm/s². What will be the acceleration of the body if it is pulled by two loops, each just like the first loop, side by side and stretched by that same amount? (See Fig. 2–10.)

10. An object sliding on a low-friction bearing is pulled with a constant force. In a time interval of 0.3 s the velocity changes from 0.2 m/s to 0.4 m/s. In a second trial, the object is pulled with another force. In the same length of time the velocity now changes from 0.5 m/s to 0.8 m/s.
   (a) What is the ratio of the second force to the first?
   (b) If the body is pulled with the second force for 0.9 s, what change in velocity results?

23. A block is pulled along a horizontal surface by 2, 4, 6, and 8 parallel bands of rubber. All bands are alike and each is stretched the same length in each experiment. The graph (Fig. C) shows the resulting accelerations plotted versus the number of bands.
   (a) What can you conclude from the fact that the plot yields a straight line?
   (b) What does the intercept of the graph with the horizontal axis measure?
   (c) Can you use the graph to predict the acceleration of the block produced by stretching one rubber band by the standard amount?
   (d) Suppose you repeat the experiment, changing only the surface on which the block is pulled. How will the new graph relate to the old one?

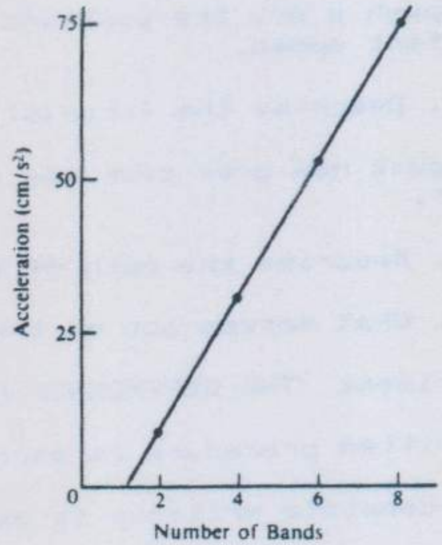


Figure C

12. A car can accelerate by 3 m/s². What is its acceleration if it is towing another car like itself?

14. (a) Suppose two pucks identical with the puck of Fig. 2–8 are joined together, and are pulled by two loops in parallel as in Fig. 2–11. How does the acceleration of this double puck compare with the acceleration of the puck in Fig. 2–9?
   (b) Suppose three such pucks are joined together, and are pulled by two loops arranged as in Fig. 2–11. How does the acceleration of this triple puck compare with the acceleration of the puck in Fig. 2–9?

15. The engine of a truck accelerates the truck when it is empty at three times the acceleration as when it is fully loaded. What is the ratio of the inertial mass of the loaded truck to that of the empty truck?

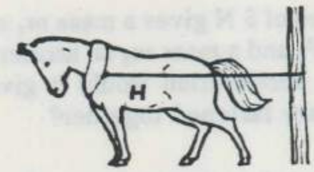
16. Why have we made such careful distinctions between gravitational and inertial mass, rather than talking about one mass only?

17. A carton is balanced by two identical cans on a balance. A certain force accelerates the carton by 2 m/s². How much will the same force accelerate one of the cans?

11. Whenever a horse pulls on a cart, the cart exerts a force on the horse equal in value to the force that the horse exerts on the cart but in the opposite direction. How do they ever progress?

If you are bothered by the question, obtain sheet titled HORSE CART PARADOX and read on. The article is taken from "Physics for the Inquiring Mind" by Eric Rogers - page 146.

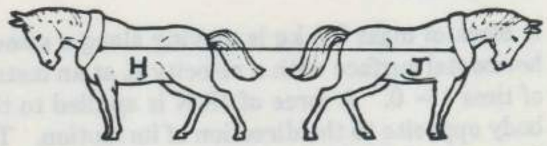
12. A horse pulls on the rope with such a force that if it pulled any harder, the rope would break. Now if the wall is replaced by a horse identical to the first horse,



a. Will the rope break?

b. If horse 'H' pulls a little harder, what will happen?

c. Still don't understand, ask instructor for assistance.



13. Problems: page 34: #9 #10
page 38: #23

14. Read: Section 2-5 Newton's Law: Inertial Mass page 34
Section 2-6 Inertial and Gravitational Mass page 36

15. Problems: page 36: #16
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17. When you completed the experiment Dependence of Acceleration on Force and Mass, you should have found that $F/a \propto m$ or that $F = kma$. In Section 2-7 of the text you found that $F = ma$.

a. Why was 'k' omitted (given a value of one) in Section 2-7?

b. What is the unit of force?

c. Note...Study Notes titled UNITS OF FORCE may be of value.

d. How big is a Newton of force? (Ask to see one.)

e. A pound of force (weight) = _______ Newton(s).

Refer to experimental results of weight vs mass in Packet B.

18. A grapefruit of mass 0.5 kg is accelerated at 10 m/s^2. How large is the force acting on it?

19. A baseball has a mass of 0.10 kg. A good pitcher can throw it at a speed of 45 m/s. If it takes him 0.15 s to accelerate the ball, what force was he exerting on the ball?

25. A force of 5 N gives a mass m_1 an acceleration of 8 m/s^2, and a mass m_2 an acceleration of 24 m/s^2. What acceleration would it give the two when they are fastened together?

27. The graph in Fig. D shows the velocity, along a straight line, of an object of mass 2 kg, as a function of time. Plot a graph of the force as a function of time.

28. A block of mass 3.0 kg is moving along a smooth horizontal surface with a velocity v_0 at an instant of time $t = 0$. A force of 18 N is applied to this body opposite to the direction of its motion. The force slows the block down to half its original velocity while it moves 9.0 m.

(a) How long does it take for this to occur?
(b) What is v_0?

20. A Dry Ice puck of mass 1.0 kg is sliding at 1.5 m/s over a smooth surface. A force of 3.0 N acts on the puck in the direction of its motion for 2.0 s. What is the final velocity of the puck?

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30. A block of mass 8.0 kg, starting from rest, is pulled along a horizontal tabletop by a constant force of 2.0 N. It is found that this body moves a distance of 3.0 m in 6.0 s.

(a) What is the acceleration of the body?
(b) What is the ratio of the applied force to the mass?
(c) Since your answer to part (b) is not equal to that to part (a) (at least, it shouldn't be), what conclusions can you draw about this motion? Give numerical results, if possible.

31. Aristotle thought that a constant force was required to produce a constant velocity and from this he concluded that, in the absence of force, bodies would come to rest.

(a) Name several situations where a constant force seems to produce a constant velocity.
(b) How do you explain each of the situations in (a) in the light of Newton's law of motion?

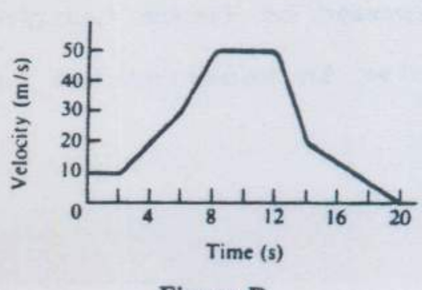

Figure D

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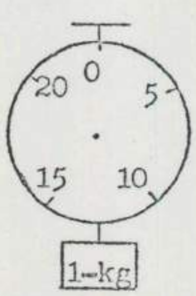
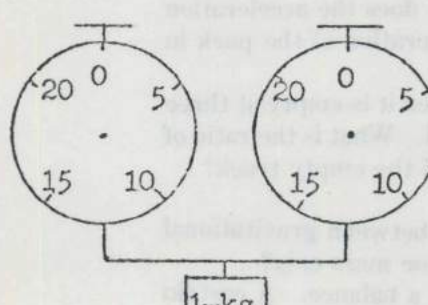
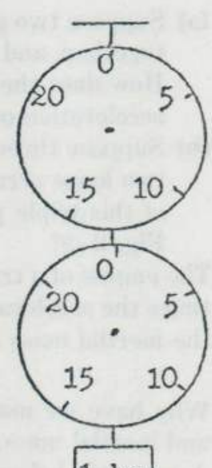


[Fig. 1]



[Fig. 2]



[Fig. 3]

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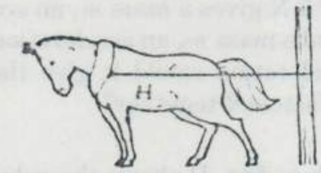

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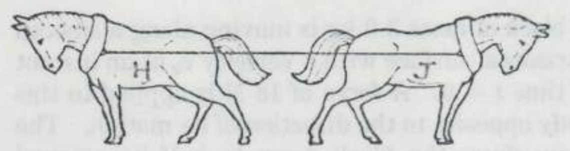

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    a. Why was 'k' omitted (given a value of one) in Section 2-7?

    b. What is the unit of force?

    c. Note...Study Notes titled UNITS OF FORCE may be of value.

    d. How big is a Newton of force? (Ask to see one.)

    e. A pound of force (weight) = ________ Newton(s).

    Refer to experimental results of weight vs mass in Packet B.

Change

CHANGES IN VELOCITY WITH A CONSTANT FORCE

We know qualitatively from everyday experiences that we must apply a force to move an object from rest or to change its velocity while it is moving, but we are not so sure of the quantitative relation between how the velocity changes and the force applied. We can investigate this relation with the apparatus shown in Fig. 1. Be sure to clamp the bumper tightly to the table so that it can stop the cart. Also clamp the timer to the table so that it does not move as the paper tape moves through it.

The experiment is best performed on a smooth LEVEL table. However, the tables are fastened to the floor, so we must use them as they are.

Before making runs to find how the velocity changes with a constant force, you should be sure that the cart moves with a nearly constant speed when you do not pull it. To find out, load the cart with 2 books and make a couple of tapes with the timer, first giving an initial push using a small force and then a second initial push with a larger force. Plot the velocity vs time (use 6 time intervals) (0.1 sec) for the two tapes on the same axis. When is the velocity more uniform?

The cart, loaded with books and running on roller-skate wheels, can be pulled forward with a constant force by hand. However we must be sure that the force is constant. We will use rubber band(s) stretched a constant length to assure that a constant force is applied to the cart. A record of the cart's motion will be made using the paper timer. From the tapes we can determine the velocity for equal time intervals during the run. Next plot a graph of velocity as a function of time. Results? Conclusion?

Examine each rubber band for cracks or weak points before using them. Also if you use more than 1 rubber loop, choose ones that have similar lengths.

Now we are ready to study the effect of a constant force on the motion of the cart. Attach one end of a single rubber loop to the round metal bar. Hook the other end of the rubber loop over the end of the meter stick. While your partner holds the cart (plus 2 books), extend the meter stick forward along side, or above the cart until the rubber loop stretches to a given length - say 25 to 40 cm. Use a reasonable force lest the cart be put into orbit. Your partner starts the timer and a few seconds later, on signal, releases the cart. You move forward, pulling the cart while keeping the rubber loop stretched a UNIFORM distance. Practice until you can keep a UNIFORM distance before making taped runs. (Do not let the meter stick come in contact with cart or books during the run.)

Make sure rubber band stretched Same amount,

Make 2 tapes, one with 2 books and then one with 4 books on the cart. Calculate the velocity for each 6 time intervals (0.1 sec) and plot the velocity as a function of time for both sets of data on the SAME axis. What do you conclude about the acceleration produced by a constant force? How does changing the mass affect the acceleration?

Can you suggest to your instructor a shortcut method compared to the one you have just used to determining the acceleration? If not, ask for an explanation.

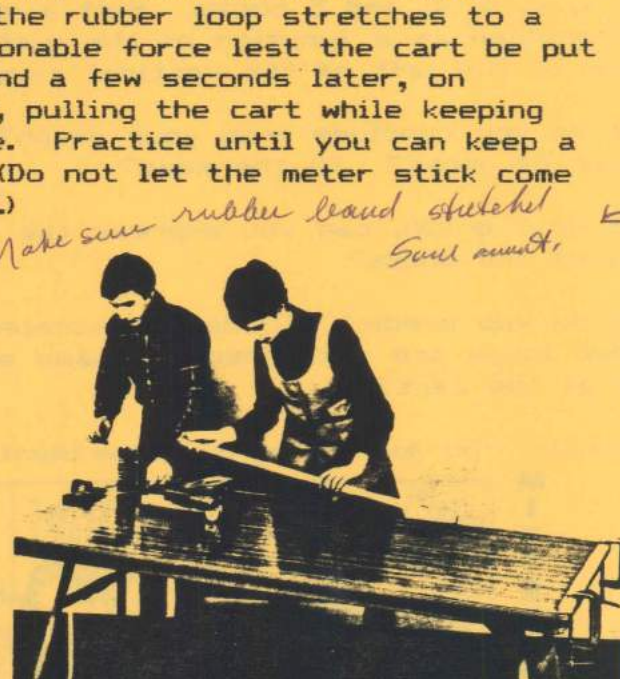


Figure 1

The Dependence of Acceleration on Force and Mass

The change in velocity of an object is proportional to the time interval during which a constant force acts on it. In other words, a constant force produces a constant acceleration. This we found in the last experiment. Here we shall investigate quantitatively how different forces accelerate a given mass and how a given force accelerates different masses.

ACCELERATION CAUSED BY DIFFERENT FORCES

Using one, two, three, four, and five rubber loops to produce the accelerating force, make tape recordings of the motion of the cart when it is loaded with four books. Find the acceleration from the tapes and plot a graph of acceleration as a function of the force, that is, the number of loops.

Since we know from the last experiment that the acceleration is constant for a constant force, it is not necessary to calculate the acceleration for many different intervals in the same run. Find the acceleration from the change in velocity during two equal time intervals that do not include the start of the tape where the data cannot be resolved. (Do not use a distance so long that it includes the last part of the motion, where it is difficult to keep the force constant.)

What do you conclude from your graph? What can you say about the ratio of force to acceleration in this part of the experiment?

Assuming no friction in the apparatus, should the graph pass through the origin? Where, with respect to the origin, would you expect your graph to pass?

THE EFFECT OF MASS ON THE ACCELERATION PRODUCED BY A CONSTANT FORCE

With one rubber loop find the acceleration of the cart when it is loaded with one, two, three, four, and five books. Plot a graph of the <u>ratio</u> of force to acceleration as a function of the number of books. **

What do you conclude from your graph? Is F/a directly proportional to the number of books? To the mass?

From your graph, can you express the mass of the cart alone in terms of the mass of the books?

**When you draw the axis, leave some space to the left of the vertical axis.

Units of Force

For the first time, you are confronted with the fact that a combination of units can be equal to a new unit or another combination of units. For example you will find that the unit of force, the Newton (Nt), equals one 'kilogram-meter per second squared' ($kg\text{-}m/sec^2$); or that acceleration, for which you usually have units of m/sec^2, can equivalently have units of Nt/kg (Newtons per kilogram).

The Newton as a unit of force is defined purely for the physicist's convenience, and its origins are found in Newton's law which says that $F = ma$. Because of Newton's law we could say that:

(unit of force) = (unit of mass) x (unit of acceleration)

Thus a perfectly valid unit of force is:

$$(\text{mass}) \times (\text{acceleration}) = kg \times m/sec^2 = kg\text{-}m/sec^2$$

So for reasons of conciseness, we simply <u>define</u> one newton as the force needed to accelerate a mass of one kg at a rate of $1\ m/sec^2$. Thus:

$$1\ Nt = 1\ kg - m/sec^2$$

Having defined the Newton in this manner, we must always remember the definition, or things can get very confusing. For instance, since

$$F = ma$$

we can write:

$$a = F/m$$

and immediately come to the conclusion that a perfectly valid unit of acceleration is force divided by mass or Nt/kg. This is a correct conclusion, for 1 Nt/kg is exactly equal to $1\ m/sec^2$, as we will now proceed to demonstrate:

Since $1\ Nt = 1\ kg\text{-}m/sec^2$, we may write:

$$1\ Nt/kg = 1\ kg\text{-}m/sec^2 \times 1\ \ 1/kg = 1\ kg\text{-}m/sec^2\text{-}kg$$

By cancelling units of kg we see that:

$$1\ kg\text{-}m/sec^2\text{-}kg = 1\ m/sec^2 \qquad (\text{Thus } 1\ Nt/kg = 1\ m/sec^2)$$

If you run across seemingly nonsensical units when solving problems, try substituting $1\ Nt = 1\ kg\text{-}m/sec^2$ into your expression. This will hopefully make matters a bit more understandable.

Note...The symbol for a Newton has been given as (Nt). Under the International System of Units (SI) the symbol for a Newton is (N). Do be aware of this symbol as new books will probably be using it.

INERTIAL AND GRAVITATIONAL MASS

The gravitational force on a body is proportional to its mass. As a consequence we can measure a mass by measuring the gravitational force on it; that is, we can determine the mass of a body by weighing it either with a spring balance or by comparing the gravitational force on one mass with that on a standard mass by use of an equal arm balance.

Another procedure for measuring mass is suggested by experience. When a given force is applied sequentially to bodies which are free to move but which have different masses, the greater the mass the less the acceleration produced by that force. We can generalize this experience and define mass in terms of the acceleration produced by a given force. If m_1 is the mass of body 1 and m_2 the mass of body 2, we *define* the ratio of the masses to be

$$\frac{m_1}{m_2} = \frac{a_2}{a_1}$$

where a_2 is the magnitude of the acceleration of body 2 and a_1 is the magnitude of the acceleration of body 1 produced by the same applied force F. If body 2 has only half the acceleration of body 1, when both are acted on by the same force, then by definition m_2 is twice as great as m_1. If m_1 is a standard mass, then m_2 would be two standard masses. If we change the force from F to F′ and again measure the ratio of the accelerations produced on the same two bodies we find the ratio of the masses to be the same, regardless of the particular force used in the experiments. Experiment shows that we can consistently assign mass numbers to any body by this procedure.

To find a number to assign for the mass of a body, we agree to assign to a standard object, which is given an acceleration of 1 meter/sec^2 by a unit force, a mass of one unit. Then the masses of all other objects are defined by

$$\frac{m_1}{m_2} = \frac{a_2}{a_1}$$

in terms of this unit mass. Thus, we have an operational procedure for the quantitive measure of mass which is simple, self-consistent, and intuitively satisfactory.

We can summarize the above in one equation, the fundamental equation of classical mechanics,

$$F = mA.$$

The question arises whether the two methods discussed above for determining the mass of a body really measure the same property. The word mass has been used in two quite different experimental situations.

If we try to push a block of ice from rest along a horizontal frictionless surface, some effort is required. The block seems to be inert and tends to stay at rest or if it is moving it tends to keep moving without either a change in its speed or direction of motion. Gravity does not enter here at all. It would take the same effort to accelerate the block of ice in gravity-free space. It is the mass of the block which makes it necessary to exert a force to change its motion. This is the mass occurring in $F = mA$. We call this mass m the *inertial mass*.

There is a different situation which involves the mass of the block of ice. Effort is required to hold the block at rest above the earth. If we do not support it, the block will fall to the earth with accelerated motion. The force required to hold the block up is equal in magnitude to the force of gravitational attraction between it and the earth. Here inertia plays no role whatever but the property of material bodies, that they are attracted to other bodies such as the earth, does play a role. The force is given by

$$F = G\frac{m^1 M_e}{R_e^2}$$

where m^1 is the *gravitational mass* of the block.

Are the *gravitational mass* m^1 and the *inertial mass* m of the block really the same?

Consider two particles A and B of gravitational masses $m_A{}^1$ and $m_B{}^1$ acted on by a third particle C of gravitational mass $m_C{}^1$. Let the third particle be at equal distance r from the other two. Then, the gravitational force exerted on A by C is

$$F_{AC} = G\frac{m_A{}^1 m_C{}^1}{r^2},$$

and the gravitational force exerted on B by C is

$$F_{BC} = G\frac{m_B{}^1 m_C{}^1}{r^2}$$

The ratio of the gravitational forces on A and B is the ratio of their gravitational masses; that is,

$$\frac{F_{AC}}{F_{BC}} = \frac{m_A{}^1}{m_B{}^1}$$

Now suppose that the third body C is the earth. Then F_{AC} and F_{BC} are what we have called the *weights* of A and B.

$$\text{Hence, } \frac{W_A}{W_B} = \frac{m_A{}^1}{m_B{}^1}$$

Therefore, the law of universal gravitation contains within it the result that the weights of various bodies, at the same place on the earth, are exactly proportional to their *gravitational masses*.

Now suppose we measure the inertial masses m_A and m_B of the particles A and B by dynamical experiments. Allow these particles to fall to the earth from a given place and measure their accelerations. We find experimentally that objects of different *inertial masses* all fall from a given place with the same acceleration g arising from the earth's gravitational pull which is their weight.

Using the second law of motion we obtain

$$W_A = m_A g$$
$$W_B = m_B g$$
$$\text{or} \frac{W_A}{W_B} = \frac{m_A}{m_B}.$$

That is, the weights of bodies at the same place on the earth are exactly proportional to their *inertial masses*. Hence, inertial mass and gravitational mass are at least proportional to one another. In fact, they appear to be identical.

Newton devised an experiment to test directly the apparent equivalence of inertial and gravitational mass. He made a pendulum bob in the form of a thin shell into which he placed different substances, being careful always to have the same weight of substance as determined by a balance. Hence, in all cases the force on the pendulum was the same at the same angle. Because there was no change in the external shape or surface of the bob, the air resistance on the moving pendulum was always the same.

In the derivation of the period of a simple pendulum, we find that for small angles

$$T = 2\pi \sqrt{\frac{ml}{m^1 g}}$$

where m is the inertial mass and m^1 is the gravitational mass of the pendulum bob. Thus $m^1 g$ gives the gravitational pull on the bob. Only if we assume that m equals m^1 do we obtain the expression

$$T = 2\pi \sqrt{\frac{l}{g}} \text{ for the period.}$$

As one substance replaced another inside the bob, any difference in the acceleration could only be due to a difference in the *inertial* mass. Such a difference would result in a change in the period of the pendulum. But in all cases Newton found the period of the pendulum to be the same, always given by $T = 2\pi \sqrt{l/g}$. Hence, he concluded that $m = m^1$ and that inertial and gravitational masses are equivalent.

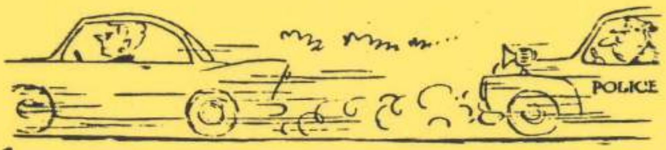
In 1909, Eotvos devised an apparatus which could detect a difference of 1 part in 100 million in gravitational force. He found that equal inertial masses always experienced equal gravitational forces within the accuracy of his apparatus.

In classical physics this equivalence was looked upon as a remarkable accident having no deep significance. But in modern physics it was an important clue leading to the development of the general theory of relativity.

The original of the above development is to be found in "Physics for Students of Science and Engineering" by Halliday and Resnick, published in 1960 by John Wiley and Sons, New York, New York. See pages 325-327, 69-72 and 295-297.

Halt In The Name Of... Crash!

By SYVERSON



1

2

3

WRITTEN EXERCISE CHAPTER 2 -1-

1. Suppose you accelerate an object with a constant force and find that the change in speed during a time interval of 4 seconds amounts to 3.6 m/sec. You now repeat the measurement using the same force with a second object. It gains 6.6 m/sec in 0.25 sec. (a) Which body has the greater mass? (b) What is the ratio of the inertial mass of the second object to that of the first?

   a. ____________

   b. ____________

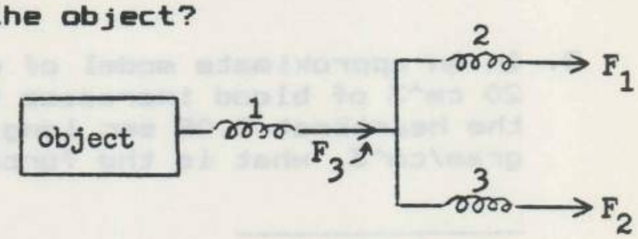
2. A force of 12 Newtons gives a mass an acceleration of 12 m/sec/sec, and a second mass an acceleration of 24 m/sec/sec. What acceleration would it give the two masses when they are fastened together?

   ____

3. You have two objects, 'A' and 'B', which balance each other when placed on opposite sides of an equal-arm balance. When you place these objects on one side, they balance a third object 'C' on the other side. Object 'A' accelerates at 8.4 m/sec/sec when you apply a certain force. Suppose you now apply this same force to 'C'. What is its acceleration?

   ____

4. Below you will find an object which is acted on by some forces. All springs are of identical construction (i.e. a certain force will produce the same elongation and twice the force will produce twice the elongation). Assume that $F_1 = F_2 = 18$ Newtons. How will the elongation of
   (a) spring one compare to spring two? and
   (b) spring two compare to spring three?
   (c) What is the total force acting on the object?
   (Suggestion: $F_1 + F_2 + F_3$)



   a. _______________

   b. _______________

   c. _______________

5. A block of mass 6.0 kg is pulled on a frictionless table by a constant force of 8.5 Newtons. The block starts from rest.
   a. What is the acceleration of the block expressed in m/sec/sec?
   b. What is the speed of the block when the force acts for 3 sec?
   c. What is the speed of the block when the force acts for 3 years?
   d. How far does the block travel in 2 sec?

   a. _______________

   b. _______________

   c. _______________

   d. _______________

6. A car having a mass of 1000 kg comes to a stop in 40 m. If the initial speed was 20 m/s, what average force (assumed to be constant) was supplied by the road acting on the car?

   ____

7. During a rescue at sea, a man of mass 70 kg dangles on the end of a rope attached to a helicopter. If the helicopter accelerates upward at 4 m/sec/sec, what tension must the rope be able to withstand?

   ____

8. In an approximate model of mammalian heart action, the speed of about 20 cm^3 of blood increases from 30 cm/s to 40 cm/s during a portion of the heartbeat 0.08 sec long. If the density of the blood is 1.1 gram/cm^3, what is the force exerted by the heart muscle?

   ____

Ch 2

P. S. S. C. EXPERIMENT #22'

CART AND THE "FALLING" MASS

Set up the apparatus below. You will need a pulley, dynamics cart and a vibrating recorder (60 hertz). The mass M that is driving the system should be adjusted untill it is about equal to the mass of the cart.

1. Before doing the experiment you should predict the acceleration of the cart using Newton's Second Law. This would be considered a theoretical value. The purpose of the experiment is to check up on this theoretical value.

2. Using the data on the vibrator strip, plot a graph of the speed versus the time. NOTE: The distance between the dots on the tape is a "measure" of the speed of the cart. Can you do anything to check the frequency of the vibration timer? Using the graph determine the experimental value of the acceleration of the cart.

3. Compare the value of the theoretical acceleration found in part 1 and the experimental acceleration found in part 2.

ACC E L E R A T I O N...

11.10
COPY-15

The Horse and Cart Paradox

Suppose a horse is pulling a cart along. The cart pulls the horse back as much as the horse pulls the cart forward. How do they ever progress? If you are worried

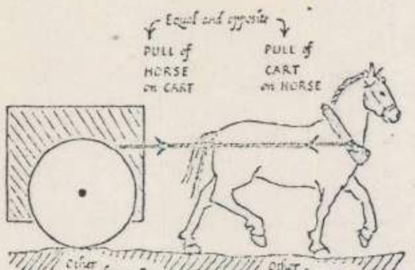


FIG. 8-13. THE HORSE AND CART PROBLEM

by this question, read the discussion below—otherwise you can omit it without serious loss.

The confusion of this "paradox" arises from failure to watch which force acts on what. Suppose the horse pulls the cart forward with 100 newtons eastward. This acts *on the cart only*, trying to accelerate it. The fact that the horse exerts this pull on the cart does not constitute a force on the horse. There *is* a force on the horse, the backward pull of the cart, 100 newtons westward, and that is a pull on the horse alone. Each of these two forces *acts on* one thing only, the thing that it pulls, the thing that it tries to accelerate; but the force is *provided* by the other thing.

The *horse provides* 100 newtons eastward,
which *acts on* the *cart*.
The *cart provides* 100 newtons westward,
which *acts on* the *horse*.

Cart. There are other forces acting on the cart, friction drags of ground and air. If the friction on the cart is just enough to balance the horse's pull, the resultant force on the cart is zero and the cart will stay at rest or move along steadily. Then

PULL OF HORSE − FRICTION DRAG = *zero*.

Therefore, no acceleration. If the horse's pull is more than the friction drag, then

LARGER PULL OF HORSE − FRICTION
= FORWARD RESULTANT FORCE,
which accelerates the cart.

Horse. Meanwhile, the horse is pulled back by the cart; and if he is to progress, he must kick the ground backwards and thus make the ground kick him forwards (another pair of equal and opposite forces). The horse, spurning the ground, is pushed forward by it. If

FORWARD PUSH OF GROUND − DRAG OF CART
− DRAG OF AIR FRICTION ON HORSE = *zero*

then the horse proceeds steadily. But if he kicks the ground harder, so that

LARGER FORWARD PUSH OF GROUND
− DRAG OF CART − AIR FRICTION
= FORWARD RESULTANT FORCE
(which acts on horse)

then he will accelerate.

"Well, then," you may object, "if I take both horse and cart together, why don't the two pulls, +100 newtons and −100 newtons, cancel?" Of course they do now. They cancel and have no more effect on the progress of the combined [horse + cart] than you have if you shake hands with yourself and tug one hand with the other when trying to run. The [horse + cart] is pushed forward by the ground acting on the horse and it is dragged back by friction drags. Its motion depends on which is greater.

Each object, [horse], [cart], [horse + cart], is acted on by several forces. Newton's Law III does not say whether the two main forces acting on any one of these are equal and opposite. It does require the forces in each pair listed in Fig. 8-14 to be equal and opposite. In each pair we have equal and opposite forces such as F and $-F$, G and $-G$, etc., but how F and G, or F and H, compare with each other is quite a different matter, no

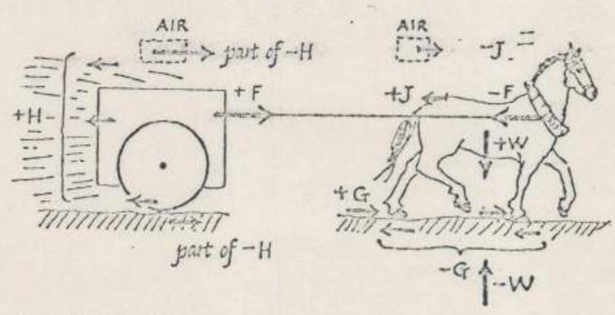


FIG. 8-14. THE HORSE AND CART PROBLEM: SETS OF FORCES

Pull of horse on cart +F Pull of cart on horse −F	are equal and opposite

and, quite separately, for horizontal forces

Horizontal shove of ground on horse +G Horizontal shove of horse on ground −G	are equal and opposite
Drag of friction on cart +H Drag of cart on ground and air −H	are equal and opposite
Drag of air on horse +J Drag of horse on air −J	are equal and opposite

and, for vertical forces,

Pull of Earth on horse +W Pull of horse on Earth −W	are equal and opposite

with a similar pair for cart and Earth.

concern of Newton's Law III. (But adding up *all the forces on one body*, such as F and H *on the cart*, will enable Newton's Second Law to predict the body's acceleration.)

PHYSICS EXPERIMENT 2021 CH. # 11

1) Determine the relationship between the following three quantities:

(A) FORCE (measured in loops: standard rubber band stretched a constant amount - check rubber bands to see that they are equal to each other

(B) MASS (measured in bricks)

(C) ACCELERATION (measured in millimeters per tock squared)

Minimum data needed:

MASS \ FORCE	1	2	3	4	TWO IN SERIES
1			II		
2	I	I	I, II	I	I (3)
3			II		
4			II		
TEXT BOOK(S)			II (2)		

I First Day in laboratory
II Second Day in laboratory

You may wish to use the computer program JHMMO to analyze your data and to plot your velocity graph.

2) Determine the mass of an unknown object (i.e. physics book) by accelerating it with a known force. (see table above)

3) Determine the effect of two rubber bands attached in series end on end. Note that in this case each rubber band must be stretched the same amount as you have been using. (see table above)

Note: You can save paper by plotting several speed vs. time curves on the same piece of paper (see experiment #1)

LAB S- ______ Name ______________________ mod ______

FORCE/MASS and ACCELERATION ON THE LINEAR AIR TRACK (Newton's 2nd Law)

I. PURPOSE: To determine the relationship between: (1) acceleration of an object and the force which caused the acceleration and (2) acceleration of an object and the mass of the accelerated object.

II. PROCEDURE: At the air track: (1) vary the acceleration of the glider by changing the amount of weight (force) on the weight hanger; collect and record data for at least 6-8 trials; then (2) vary the acceleration by changing the mass of the glider (by changing the number of gliders); collect and record data for 4 trials. Plot both sets of data: (1) acceleration as a function of force and (2) acceleration as a function of mass.

III. DATA:

ACCELERATION AS A FUNCTION OF FORCE

Force (weight on hanger) kg X 9.8	time (sec) t	t^2	distance d	acceleration a

ACCELERATION AS A FUNCTION OF THE MASS

Mass being accelerated m	t	t^2	d	a

FORMULA: $d = \frac{1}{2} a t^2$ then $a = \frac{2d}{t^2}$

DATA SHEET FOR HONORS LAB PI-10

RECORD TOTAL MASS OF THE SYSTEM (CART+CAN+"WEIGHTS") ____________

FOR TRIALS 1-4 DECREASE M1 (MASS IN THE CART) BY 100g AND INCREASE M2 (THE HANGING MASS) BY 100g. NOTE THAT M1 + M2 STAYS CONSTANT!

	TRAIL	MASS M1 (KG)	MASS M2 (KG)	DISTANCE S (M)	TIME T (SEC)	TIME SQUARED T^2 (SEC^2)
CONSTANT MASS (M1+M2=1500g)	1		.100			
	2		.200			
	3		.300			
	4		.400			

FOR TRIALS 5-8 PLACE ALL 1500g ON THE TABLE AGAIN. THEN LET M2 = 100g AND FOR EACH TRIAL AFTER 5, DECREASE M1 BY 200g (BY TAKING IT OUT OF THE CART AND PUTTING IT ON THE TABLE. NOTE THAT M1+M2 DECREASES!

CONSTANT FORCE (M2 = 100g)	5		.100			
	6		.100			
	7		.100			
	8		.100			

TABLE 10-2

	TRIAL	MASS M total (M1+M2) (KG)	INVERSE OF 1/M total (1/KG)	UNBALANCED FORCE F=M2XG (NT)	ACCELERATION $a = \frac{2s}{t^2}$ (M/SEC^2)
CONSTANT MASS	1				
	2				
	3				
	4				
CONSTANT FORCE	5				
	6				
	7				
	8				

HONORS Unit 3 WS-1 NEWTON'S LAWS Name ______________________ mod ____

1. A body of mass 2 kg is acted upon by a force of 6 nt. Find the acceleration.

   $m = 2kg$ $F = 6N$ $a = ?$ $a = \frac{F}{m} = \frac{6N}{2kg} = 3\frac{m}{s^2}$

2. If that same 2 kg has an acceleration of 4 m/sec^2, what did the force have to be to create the 4 m/sec^2 acceleration.

   $m = 2kg$ $a = 4\frac{m}{s^2}$ $F = ma$ $F = 8N$ ∴ increase by 2N

3. Calculate the mass of a body which is given an acceleration of 35 m/sec^2 when it is acted on by a force of 175 newtons.

4. A body with a mass of 300 kg is accelerated at the rate of 5 m/sec^2. Calculate (a) the force in ~~dynes~~ which produced this acceleration, and (b) the force in newtons.

5. An airplane having a mass of 8000 kg is launched by a catapult with the force of 320,000 newtons. If it takes 1.5 sec for the catapult to launch the plane, what will the plane's velocity reach?

6. In the problem above, calculate the distance the plane traveled during launching.

7. A mass of 5 kg is acted upon by a steady force of 2 nt. How far will it move (from rest) in 10 sec?

8. What force will cause a mass of 6 kg to move 37.5 m in 5 sec. (from rest)

 NEWTON'S LAWS Name ______________________ mod____

1) A given force acts on a 2 kg mass and gives it an acceleration of 3 m/sec^2. What acceleration is produced by the same force when acting on a mass of:

a) 1 kg b) 4 kg

2) Find the weight of a body whose mass is:

a) 2 kg b) 0.5 kg . c) 2 slugs

3) Determine the acceleration produced by an unbalanced force of 5 nt acting on a mass of 2 kg.

4) What unbalanced force will produce an acceleration of 2.4 m/sec^2 on a 4 kg mass?

5) Find the force required to give a block weighing 12 lb an acceleration of 8 ft/sec^2.

6) A 2000 lb automobile is speeding at 60 mi/hr (88 ft/sec). Find the retarding force of the brakes required to stop the car in 220 ft on a level road.

7) A ball thrown vertically upward returns to the starting point in 4 sec. Find the speed at which you threw the ball (i.e. the initial velocity)

Name ______________________________

26 A cart is placed on a frictionless, horizontal surface and is moved by means of elastic bands of identical structure. The mass of the cart may be changed by placing masses on it. From the graphs below, select the one which best describes distance versus time when the cart is pulled by a constant force.

(D)

27 A cart is placed on a frictionless, horizontal surface and is moved by means of elastic bands of identical structure. The mass of the cart may be changed by placing masses on it. From the graphs below, select the one which best describes acceleration versus the number of identically stretched bands pulling the cart.

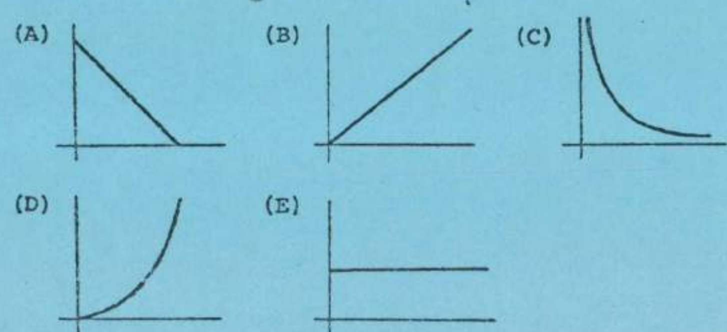
(B)

28 A cart is placed on a frictionless, horizontal surface and is moved by means of elastic bands of identical structure. The mass of the cart may be changed by placing masses on it. From the graphs below, select the one which best describes acceleration versus the mass of the cart when pulled by a constant force.

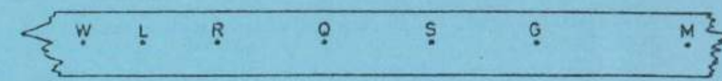
(C)

29 A cart is placed on a frictionless, horizontal surface and is moved by means of elastic bands of identical structure. The mass of the cart may be changed by placing masses on it. From the graphs below, select the one which best describes speed versus time when the cart is pulled by a force which is increasing uniformly with time.

D.



30 A tape from a laboratory experiment has the appearance shown below. The dots were made by a vibrator with a steady frequency of 20 Hz.



Choose the correct statement

(A) The speed at point Q must be equal to the average speed between W and M.

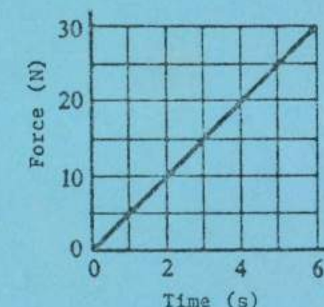
(B) The tape could have been made by a freely falling object.

(C) The tape indicates non-uniform acceleration.

(D) The tape could have been made by a constant unbalanced force acting on a given mass.

(E) The tape could not have been made by a decelerating object.

31 A steadily increasing force, acting in a fixed direction, is applied to a body of mass 4.0 kg which is initially at rest. Below is the graph of the force versus time.



The speed of the object at the end of the first 4 s is

(A) 5 m/s

(B) 10 m/s

(C) 20 m/s

(D) 22.5 m/s

(E) 40 m/s

$m = 4.0\ kg$ $v_i = 0$
$F = 20\ N$ $v_f = ?$
$a = \frac{F}{m}$ $t = 4\ sec$
$a =$
$a = \frac{v_f - v_i}{t}$
$v_f = \frac{F}{m} t$
$= \frac{20\ N}{4\ kg} \times 4\ s$ $v_f = at$