Chapter 1 Questions
Newton's Universe

1. Does a physical "law" represent the precise mechanism by which Nature actually works? Discuss.

2. How does mathematics assist in the formulation and explanation of physical law?

3. What did Newton mean by "absolute space" and "absolute time?"

4. Two physicists pass each other in a thunderstorm, traveling opposite directions on a straight, east-west road. The moment they pass, a lightning bolt strikes a tree by the highway one mile to the east, and another lightning bolt strikes a tree one mile to the west. How will each physicist describe the sequence of thunder claps from the two bolts? How can the Galilean transformation help them determine how far away the bolts struck? (They will see the lightning bolts at essentially the instant the lightning strikes, since light travels so quickly. The sound of the thunder, on theother hand, takes about 5 seconds to travel one mile.)

5. The current of the Mississippi River flows about 5 miles per hour at New Orleans. The river boat, Delta Queen, has a water speed of 10 mi/h (i.e., the boat moves at 10 mi/h relative to the water). How fast does the Delta Queen move relative to the city as it travels upstream, against the current? Draw a vector diagram to analyze the situation. How fast does the boat travel relative to the city on a trip down-river? What different frames of reference must you consider in evaluating this problem?

6. A hummingbird with an air speed of 40 mi/h takes off from Key West traveling due south toward its wintering ground in South America. The wind blows from the east with a speed of 30 mi/h relative to the Earth's surface. What is the net velocity (speed and direction) of the hummingbird relative to Earth's surface?

7. Give an example from your everyday experienceillustrating Newton's Principle of Relativity.

8. Define the following terms with mathematical symbols and a brief discussion: velocity, momentum, acceleration, force, energy.

9. What is inertia? How is it related to mass?

10. How does inertia help launch U.S. spacecraft? (Why was Cape Canaveral chosen as a launch site and not a site farther north?)

11. Imagine two bumper cars, each of one kg mass, with friction-free bearings rolling on a friction-free surface. Describe what will happen in each of the following circumstances:
    a. Car A, rolling at one meter/sec left to right collides with car B, which is initially at rest.
    b. Car A, rolling at one meter/sec from the left, collides with car B, rolling at one meter/sec from the right.

c. We add an extra 1 kg mass to car B. Car A, rolling at one m/sec from left to right, collides with car B, initially at rest.

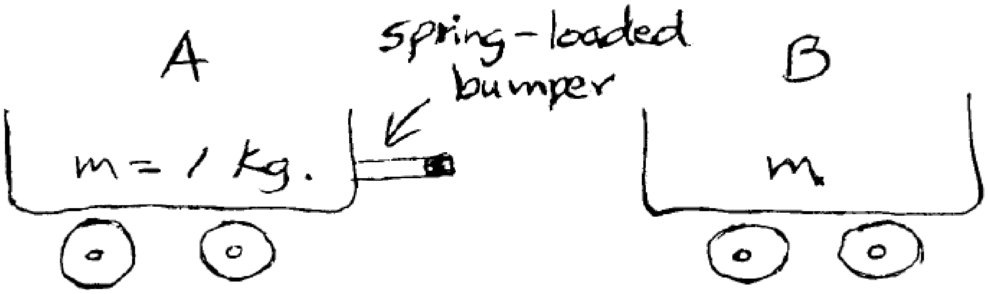


Figure Q1.1. Bumper cars.

12. Halfback Choo Choo Smith, who has a body mass of 100 kg, collides head-on with cornerback Griz Green, also a mass of 100 kg. Both were running at 10 m/sec and in opposite directions when they collided. What is the result? Choo Choo describes the impact as "like running into a brick wall." Is he exaggerating?

13. Lefty Finnegan, shortstop for the Podunk 'Possums baseball team, has loaded his bats with a lead core, claiming the increased mass transfers more momentum to the ball, so he can hit farther. Thumbs McDougal, center fielder, scoffs at the idea, saying his lighter bat transfers more momentum, because he can swing it faster. Who is correct?

14. Scientists at the National Accelerator Laboratory observe the decay of a neutron which was initially at rest in their detector. (An isolated neutron disintegrates, leaving behind other fundamental particles.) Their detector can record the tracks of electrically charged particles but not neutral particles. Among the decay products, they detect a proton and an electron, but when they measure the momenta of the proton and the electron, the momenta do not add to zero. (See illustration, next page.) What can they conclude?

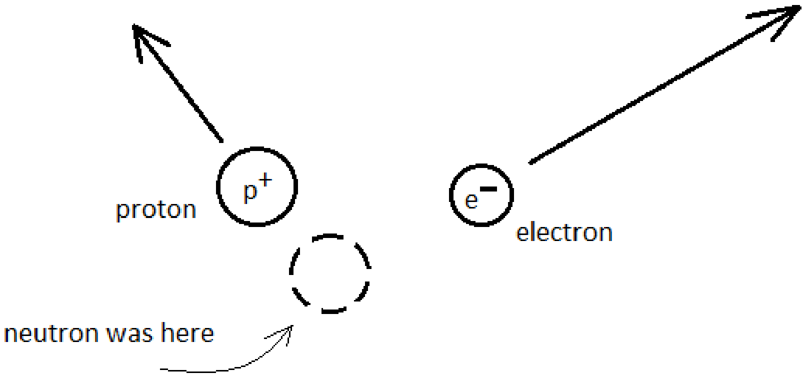


Figure Q1.2. Beta decay. Something's missing!

15. You are riding at the rim of a large merry-go-round decide to walk to the center. As you try to walk a straight line path toward the center, you notice you tend to deviate from the line: you are "pushed" in the direction of the merry-go-round's spin. Why?

16. "Newton's third law is really just a re-statement of the law of conservation of momentum." Discuss.

17. A horse pulls a cart forward. By Newton's third law, the cart pulls the horse backward with equal force. How, then, can the cart and horse move at all? (From Epstein, *Gedanken Physics*.)

18. On a moving bicycle, the bike turns left when you lean the bike to the left, even if you hold the handle bars straight ahead. Explain this phenomenon in terms of conservation of angular momentum. (And try it on a real bike.)

19. As winds approach the center of a hurricane, they speed up. Why?

20. How does the law of conservation of angular momentum explain Kepler's second and third laws?

21. "Friction" is really just a hidden transfer of momentum, hidden because it occurs at a scale too small for us to see. Suppose a baseball, with a mass of 0.5 kg, is falling through the air at terminal velocity (about 50 m/sec). Terminal velocity is the velocity at which air molecules bumping into the ball are transferring enough momentum to compensate for the force of gravity. Suppose a typical air molecule has a mass of about $1 \times 10^{-23} gm$. How many molecules strike the ball each second? Assume each molecule transfers all its momentum to the ball, the acceleration due to gravity is about 10 m/sec/sec, and there are no up-drafts or down-drafts affecting the momenta of the air molecules.

22. Tarzan wants to swing by vine from the branch of one tree to a higher branch on another tree. Jane tells him it's not possible. Why is she so pessimistic? Tarzan ponders the problem, then decides to give it a try anyway. Jane doesn't worry, because she knows at least he'll return safely to his starting point. How does she knowthis? Tarzan is determined to reach the other tree. After more thought, Jane discovers how it can be done. What does she tell him?

23. The moon has a radius about 1/4 the radius of Earth, and the mass of the moon is about 1/100th Earth's mass. How strong is the force of gravity holding an astronaut on the surface of the moon compared to the force of gravity on Earth? If an astronaut weighs 120 lb on Earth, how much would she weigh on the moon?

24. Given data, below, for period of revolution and mean distance from the sun, plot a graph of the square of the period of revolution versus the cube of the mean distance from the sun for the following planets. What is the significance of your graph in terms of Kepler's third law?

Planet	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune
Distance from Sun (AU)	0.387	0.723	1	1.52	5.20	9.58	19.20	30.05
Orbital Period (earth years)	0.241	0.615	1	1.88	11.9	29.4	83.7	163.7
Mass relative to earth	0.0553	0.815	1	0.107	317.8	95.2	14.5	17.1

Table Q1.1. Orbital data for the planets in units of earth's orbital parameters.

25. How does the force of gravity exerted by the sun on Jupiter compare to the force of gravity exerted by the sun on Earth? (Use the data given in table Q1.1.)

26. According to Newton, does gravity affect light?

27. Why does a heavy mass fall at the same rate as a small mass (neglecting the effects of friction) when they are both dropped from the same height above Earth?

28. (Computer exercise) Using the approach given in Feynman's article (p.5), plot the orbit of Earth around the sun.

29. Calculate the acceleration due to gravity at the Earth's surface, given F = ma, and F_G = Gm1m2/R^2, and R = 6400 km. The gravitational constant, G = about 6.7 X 10^-11 N-m^2/kg^2, and the mass of the Earth is about 6 X 10^24 kg.

30. Imagine two drops of water in otherwise empty space. The force of gravity between them, as given by Newton's law, will be attractive and proportional to their masses and inversely proportional to the square of the distance between them. Now imagine two bubbles in a Universe otherwise completely filled with water. Will they feel a force? What is the direction of the force? (From Epstein, *Gedanken Physics*.)

31. One high-energy physics laboratory accelerates protons (which are about 2000 times the mass of an electron) to high velocities in order to study subatomic particles. Another laboratory accelerates electrons. If the laboratories accelerate the particles to the same final velocity, which requires more energy, and why? (We shall see, in the next chapter, that energy requirements actually become comparable as the particles are accelerated to higher and higher velocities.)

32. What is meant by the term "causality?" "Objectivity?"

33. "When we look out at the stars at night, we are looking back in time." Discuss this statement. What time is it right "now" in the Andromeda Galaxy, 2.5 million light-years from us?

34. Calculate the velocity of the Earth in its orbit around the sun, given a mean distance of about 150 x 10^6 km from Earth to sun. What happens to the "Io clock" from day to day as Earth approaches Jupiter in its orbit? As Earth recedes?

35. How does Newton's notion of absolute space and time conflict with his Principle of Relativity?

36. The Earth itself behaves like a giant magnet. Knowing that electric currents create a magnetic field, what do you suppose produces the magnetic field on Earth? Draw a diagram of events in the Earth's core.

37. During a rainstorm, raindrops strip electrons from molecules in the atmosphere and deposit the electrons on the Earth's surface. Occasionally, if too many "pile up" on the ground, they discharge back into the atmosphere in a lightning bolt. Diagram the electric field in the atmosphere. Would an astronaut in orbit, above the atmosphere, detect an electric field on Earth?

38. Like gravity, the electric and magnetic fields also obey an inverse-square law, i.e. the electric and magnetic forces decrease as the inverse square of the distance from the source of the field. The electric and magnetic forces, however, are very much stronger than the gravitational force. Devise an experiment to test the relative strengths of the magnetic force and gravity.

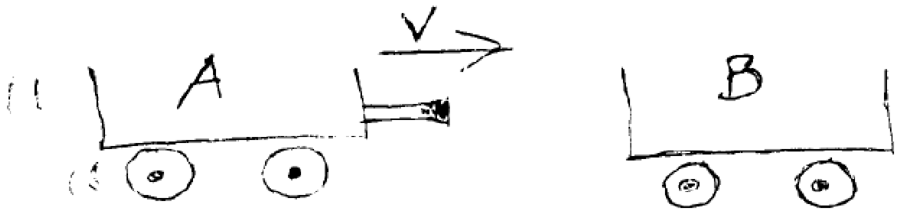
Chapter 1 Experiments

Inertia:

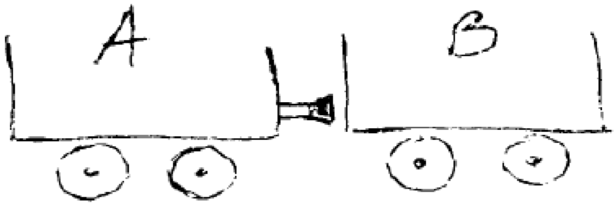
1. Lift a bowling ball, and shake it side to side. Then lift a ping-pong ball, and shake it side to side. Which has the greater inertia?

Conservation of momentum:

2. Find two bumper cars of equal mass, one of them with a spring loaded bumper. Place the cars on a level surface. With the bumper unloaded, roll one car toward the other. What happens when they collide?



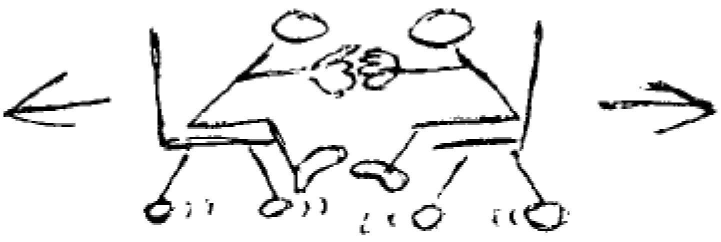
Now juxtapose the two cars, with the bumper loaded.



Trip the trigger. What happens? What do these demonstrations illustrate about conservation of momentum? (If you do not have bumper cars, two billiard balls or two marbles of equal mass will do.)

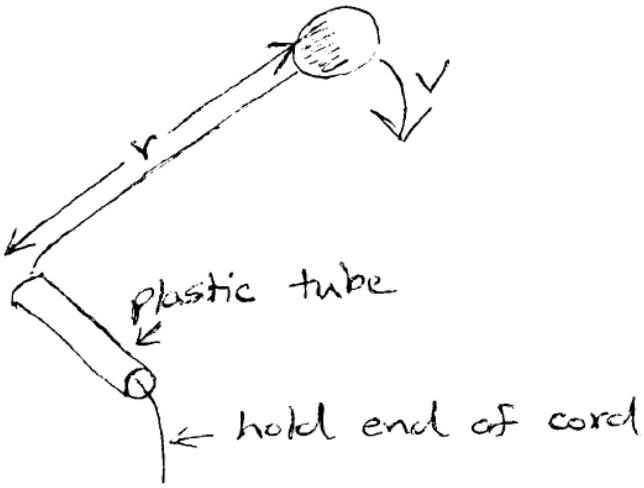
Action/reaction:

3. Seat yourself on one rolling chair, a friend on another. Push against each other. What happens? If one of you is much heavier than the other, what happens?

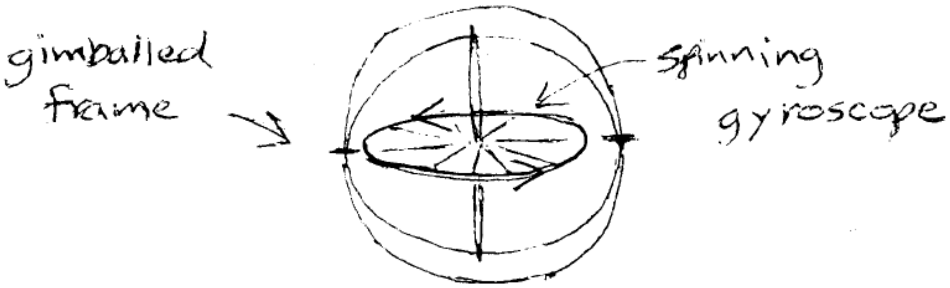


Conservation of angular momentum:

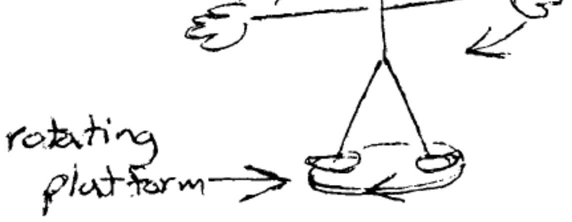
4. Tie a tennis ball on a cord, and run the cord through a sturdy plastic tube (such as a thick drinking straw). Twirl the ball, holding the tube as the pivot point. Pull the cord through the tube to shorten the radius of rotation. What happens to the speed of rotation?



5. Find a gimballed gyroscope (a gyroscope that can rotate within its frame). Spin the gyroscope with the axis pointed away from you. Turn yourself around slowly while holding the gyroscope. What happens to the direction of the gyroscope's axis as you turn around?

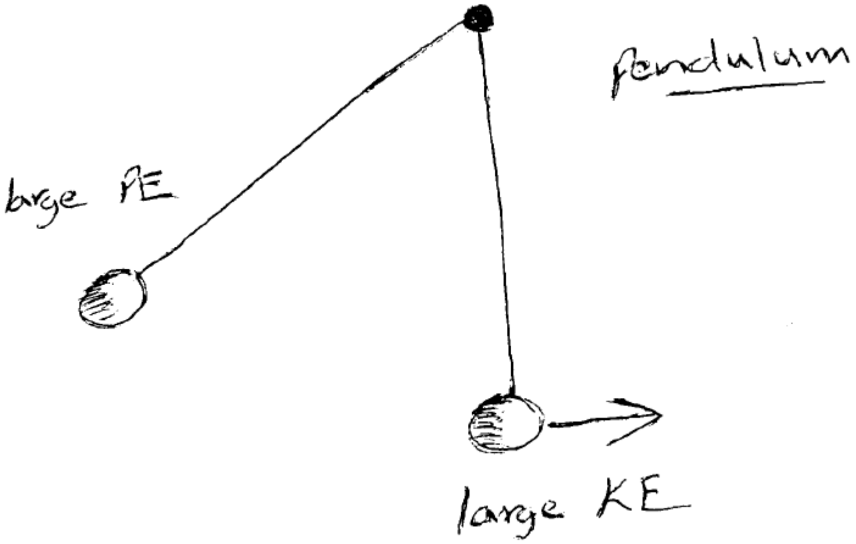


6. Find a rotating platform. Stand on it (carefully balanced) with arms outstretched. Have a friend spin you slowly. Now pull in your arms. What happens to your rate of rotation? (If you don't have a rotating platform, spinning around on a heel or toe will suffice, or spin around on a swivel chair.)



Conservation of energy:

7. Hang a pendulum on a length of cord from a sturdy support. Set the pendulum swinging, and study the motion. At what position on its swing does the pendulum have the greatest velocity (and kinetic energy, $mv^2/_2$)? At what position does the pendulum have the greatest height (and potential energy, *mgh*)? Compare pendulums of different lengths. How does the length of the string affect the period of the pendulum (the time it takes the bob to make one complete cycle, from one extreme of its swing back to the same position)?

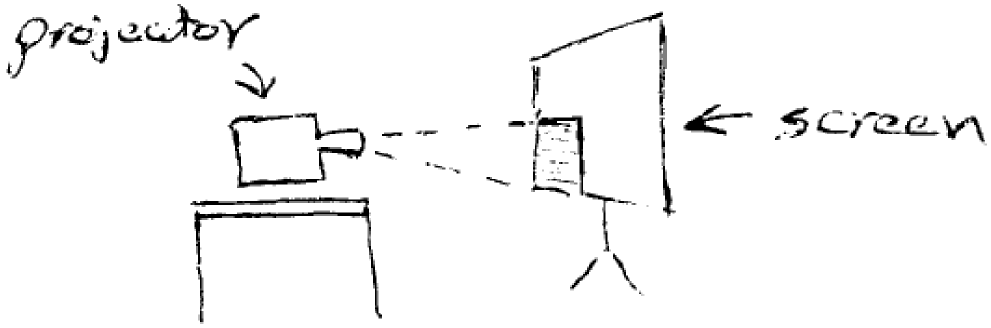


8. Find a half-pipe PVC trough, or, better, tape two meter sticks side by side and partially fold the sticks into a "V". Mark distances (in inches or cm) along the surface. Prop the trough at various slants, and measure the time it takes marbles to roll down the surface. How does the rate of fall depend on the slant? How does the rate of fall depend on the weight of the marble? See if you can determine the distance the marbles have traveled after each successive second as they roll down the surface.

Inverse square law:

9. Find a slide projector or an overhead projector and screen. Place the screen at a distance such that the square of light from the projector covers one quarter of the surface of the screen. Move the projector away from the screen to twice the original distance. How much

of the screen does the light cover now? How does this relate to Newton's Law of Gravity? (Imagine the light from the projector represents "cables" of gravity reaching across space, pulling one mass toward another.)

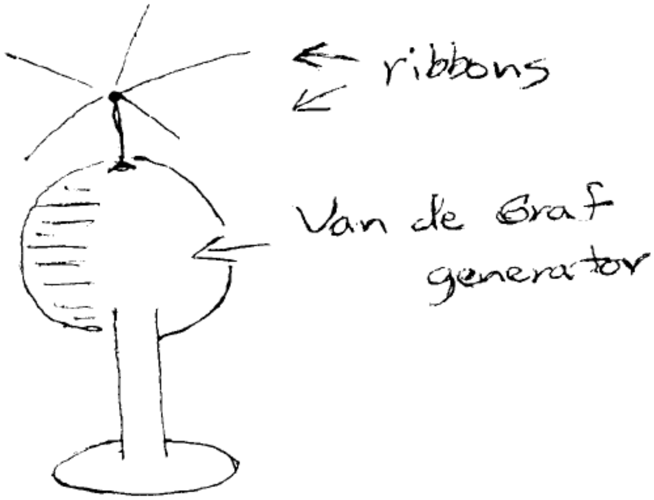


<u>Magnetic field</u>:

10. Use iron filings to outline the magnetic field around a bar magnet, as described in the text. Push the north pole of one magnet toward the north pole of the first. What happens to the field lines? Push the south pole of a second magnet toward the north pose of the first. What happens to the field lines now?

<u>Electric field</u>:

11. Demonstrate the presence of an electric field with pen and paper: charge the pen (or a glass rod) by rubbing it vigorously with a piece of cloth. Pick up bits of paper with the charged pen. If available, have your instructor assist you in charging a Van de Graf generator to demonstrate more intense electric fields. One method of outlining the field is to attach ribbons to the generator with a rubber suction cup: the ribbons outline the field.



12. Here's another good demonstration of the electric field and the separation of positive and negative charges. You and a friend both do the following: Tear off a piece of scotch tape about 10 cm (4 inches) long. Fold over one end, to create a non-sticky tab. Lay the tape with its adhesive down on a smooth, clean desk surface, and label it $+$. Prepare another piece of tape same way. Place it on top of the $+$ tape, and label it $-$. Gently press down on the two pieces so they stick to each other, then remove them from the desk top. Grasp the tabs, and tear them apart quickly. Try not to let the two pieces of tape touch each other. Now you're ready for some experiments:

    a. What happens to the $+$ and $-$ tapes when you bring them close to each other?
    b. What happens when you bring your $-$ tape close to your friend's $-$?
    c. What happens when you bring your $+$ tape close to your friend's $+$?

    Try other combinations. Explain your results.

<u>Magnetic induction</u>:

13. Perform the demonstrations of electromagnetic induction outlined in the text: thrust a bar magnet through a coil of copper wire to induce an electric current, and then create a magnet by running electric current through a coil wrapped around an iron bar.