Passage 1 (Questions 1-5)

[You do not need to have any prior knowledge of electricity to deal with this passage.]

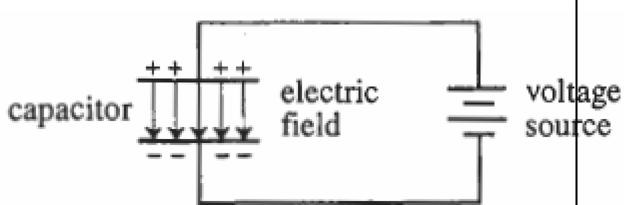
In a parallel-plate capacitor, two parallel metal plates are connected to a voltage source which maintains a potential V across the plates. Positive charges collect on one side of the capacitor and negative charges on the other side, thus creating an electric field $\vec{E}$ between the plates. The magnitude of the electric field is related to the potential and the separation between the plates according to

$$V = Ed,$$

where V is measured in volts, E in J/m, and d in m. A charged particle placed between the plates will experience a force given in magnitude by

$$F = qE,$$

where q is the charge of the particle in Coulombs, and F is the force in N.



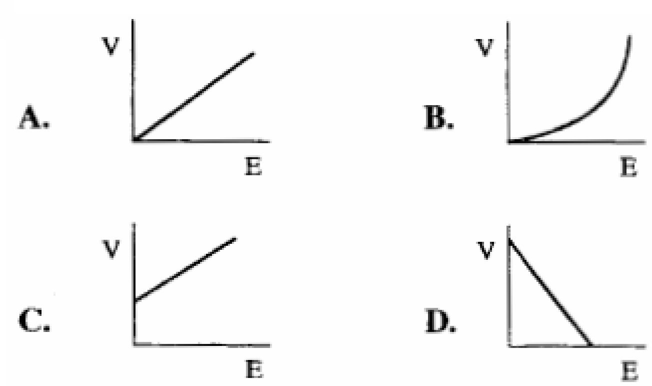
1. If a new battery is installed, so that the voltage between the plates is increased by a factor of 9, how is the electric field affected?
   A. It decreases by a factor of 9.
   B. It increases by a factor of 3.
   C. It increases by a factor of 9.
   D. It increases by a factor of 81.

2. If the voltage in a given experiment is held constant, but the distance between the plates is increased by a factor of 3, how is the electric field affected?
   A. It decreases by a factor of 9.
   B. It decreases by a factor of 3.
   C. It stays the same.
   D. It increases by a factor of 3.

3. In a given experiment, both a proton and a bare helium nucleus are between the plates. How does the force on the helium nucleus compare to the force on the proton?
   A. It is the same.
   B. It is twice as great.
   C. It is four times as great.
   D. There is no force on the helium.

4. In a given experiment, all other things being held constant, what happens to the force on a proton between the plates if the separation of the plates is increased by a factor of 2?
   A. It decreases by a factor of 4.
   B. It decreases by a factor of 2.
   C. It stays the same.
   D. It increases by a factor of 2.

5. Which graph best show the relationship between the potential V and the electric field E?



Passage 2 (Questions 6-11)

Two charged balls which are near each other will exert a force on each other: attractive if they are oppositely charged, and repulsive if they are similarly charged. The magnitude of the force is given by

$$F = \frac{kq_1q_2}{r^2},$$

where F is in N, k is a constant 9×10^9 N m^2/C^2, q_1 and q_2 are the charges on the balls measured in C, and r is the distance between the balls in m.

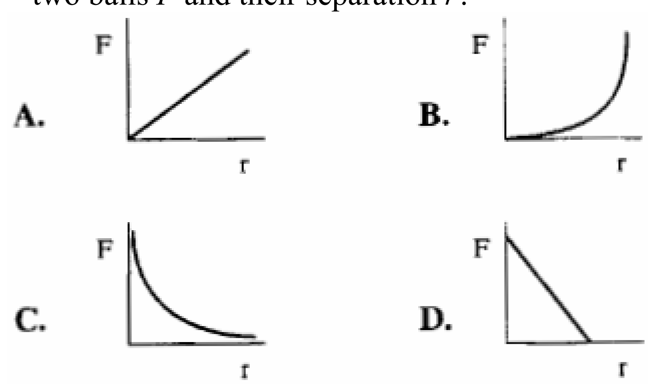
6. In a certain experiment, the separation between the balls is halved, while the charges on the balls are undisturbed. How would this affect the force between them?
A. The force would decrease by a factor of 4.
B. The force would decrease by a factor of 2.
C. The force would increase by a factor of 2.
D. The force would increase by a factor of 4.

7. In an experiment, the distance separating the balls is increased by 25%. How does this affect the force between the balls?
A. It decreases by 50%.
B. It decreases by 36%.
C. It decreases by 25%.
D. It increases by 25%.

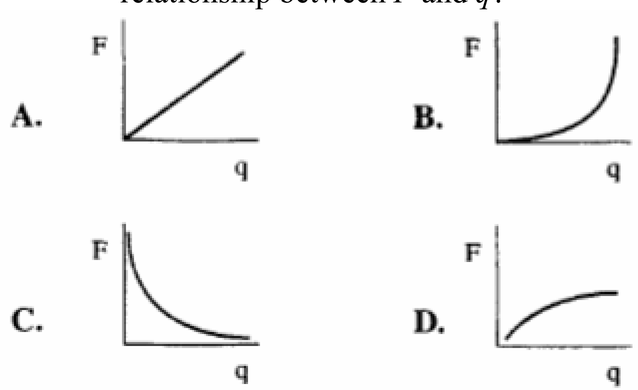
8. If the force between the balls stays the same, but the charge q_2 is multiplied by 4, which is a possibility?
A. The charge q_1 is also multiplied by 4, and all else is unchanged.
B. The separation is decreased by a factor of 2, and all else is unchanged.
C. The separation is increased by a factor of 2, and all else is unchanged.
D. The separation is increased by a factor of 4, and all else is unchanged.

9. In a hypothetical situation, two balls of positive charge exert a force 12 N on each other. The charge on ball A is 2 C. if the charge on ball A is increased to 8 C, and all else unchanged, what would the force be?
A. 8 N
B. 16 N
C. 18 N
D. 48 N

10. Which graph best shows the relationship between the force between two balls F and their separation r?



11. In a certain experiment two balls are both given a charge *q*, they are set a distance *r* away from each other, and the force between them is recorded. Which graph best represents the relationship between *F* and *q*?



Passage 3 (Question 12-15)

In a certain experiment, we are investigating the retarding force that a fluid exerts on an object moving through it. We guess that the size of the object is a factor, so we include *A*, the cross-sectional area, in an equation. The relative velocity between the object and the fluid is a factor *v*, as well as the density of the fluid ρ. So we guess

$$F = k\rho^m A^n v^p \,,$$

where *k* is a proportionality constant with some appropriate units. Before we run the experiment, we do not know the values of the exponents *m, n* and *p.*

The chart gives the data for a certain fluid.

Experiment	Object	*A* (cm^2)	*v* (m/s)	*F* (N)
1	Cock ball	1.5	7.0	0.020
2	Cock ball	1.5	3.5	0.005
3	Steel ball	1.5	3.5	0.005
4	Steel ball	3.0	3.5	0.010
5	Steel ball	4.5	3.5	0.015
6	Steel ball	3.0	14.0	0.160

12. Which pair of experiment could be used to determine *n*?
A. 2 and 3
B. 3 and 4
C. 4 and 6
D. 5 and 6

13. What is the approximate value of *p*?
A. 2 and 3
B. 3 and 4
C. 4 and 6
D. 5 and 6

14. Which pair of experiments indicates that retarding force does not depend on the density of the object?
A. 1 and 2
B. 2 and 3
C. 1 and 6
D. 4 and 6

15. Let us say *m* and *n* are known. What combination of experiments would be considered a minimum set for determining *p* and *k*?
A. 1 and 2
B. 1, 2, and 3
C. 3, 4, and 5
D. 3 only

Passage 4 (Questions 16-20)

The amount of energy a car expends against air resistance is approximately given by

$$E = 0.2\rho_{air} ADv^2 ,$$

where E is measure in Joules, ρ_{air} is the density of air (1.2 kg/m^3), A is the cross-sectional area of the car viewed from the front (in m^2), D is the distance traveled (in m), and v is the speed of the car (in m/s). Julie wants to drive from Tucson to Phoenix and get good gas mileage. For the following questions, assume that the energy loss is due solely to air resistance, and there is no wind.

16. If Julie increases her speed from 30 mph to 60 mph, how does the energy required to travel from Tucson to Phoenix change?
A. It increases by a factor of 2.
B. It increases by a factor of 4.
C. It increases by a factor of 8.
D. It increases by a factor of 16.

17. Julie usually drives at a certain speed. How much more energy will she use if she drives 20% faster?
A. 20% more energy.
B. 40% more energy.
C. 44% more energy.
D. 80% more energy.

18. Scott drives a very large 50s style car, and Laura drives a small 90s style car, so that every linear dimension of Scott's car is double that of Laura's car. *On the basis of energy loss due to air resistance alone,* how much more energy would you expect Scott's car to expend getting from Tucson to Phoenix than Laura's car?
A. Twice as much as energy.
B. Four times as much energy.
C. Eight times as much energy.
D. Sixteen times as much energy.

19. How does Julie's energy usage change if she changes from driving 50 mph to 55 mph?
A. It increases by 10%.
B. It increases by 20%.
C. It increases by 21%.
D. It increases by 40%.

20. Julie modifies her car, so that the effective cross-sectional area is reduced by 20%. How much further can she drive and still use the same amount of energy?
A. 10% further.
B. 20% further.
C. 25% further.
D. 44% further.

Passage 5 (Questions 21- 26)

A man is driving out of his driveway by backing up. He realizes he has forgotten his lunch, so he pulls back into the driveway. Car experts agree that the best way to do this is to press on the brake until the car comes to a complete stop, shift from reverse into first gear, then accelerate forward.

The driver, however, shifts into first gear while the car is rolling backward and pushes on the accelerator until he is going forward. This causes some wear on the transmission. The following chart shows some data about his progress. (Negative velocity = backwards.)

t (s)	*x* (m)	*v* (m/s
0.0	1.35	-1.8
0.5	0.60	-1.2
1.0	0.15	-0.6
1.5	0.00	0.0
2.0	0.15	0.6
2.5	0.60	1.2
3.0	1.35	1.8

21. What is the value of his initial velocity?
A. -1.8 m/s
B. 0.0 m/s
C. 1.2 m/s
D. 1.8 m/s

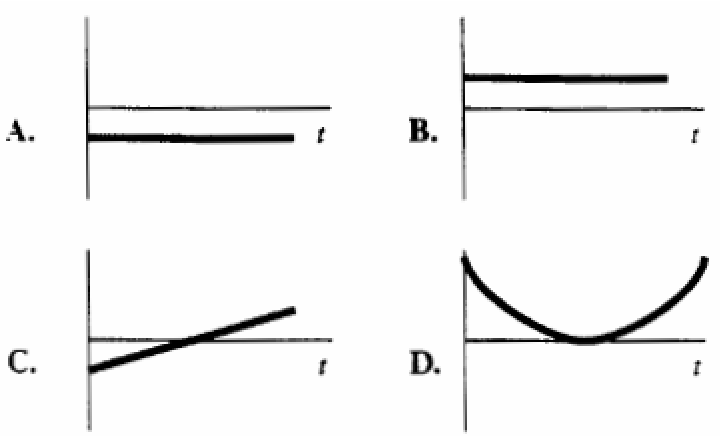
22. What is the value of his average velocity?
A. -1.8 m/s
B. 0.0 m/s
C. 1.2 m/s
D. 1.8 m/s

23. Which of the following is evidence that the acceleration is uniform?
 A. The displacement x is always nonnegative.
 B. The velocity is always increasing.
 C. The velocity becomes zero at t = 1.5 s.
 D. Equal intervals of time correspond to equal intervals of velocity.

24. What is the magnitude of the acceleration from t = 1.0 s to 2.0 s?
 A. 0.0 m/s^2
 B. 0.6 m/s^2
 C. 1.0 m/s^2
 D. 1.2 m/s^2

25. What is the direction of the acceleration vector?
 A. Forward
 B. Backward
 C. Up
 D. Down

26. Which best represents the graph of acceleration versus time?



Passage 6 (Questions 27- 33)

A physics student leans out of the fortieth story of the physics building and drops two balls of the same size at the same time. One is 0.8 kg and made of iron, and the other is 1.2 kg and made of lead. Not only do the two balls hit the ground at the same time, the heights of the two balls match all the way down.

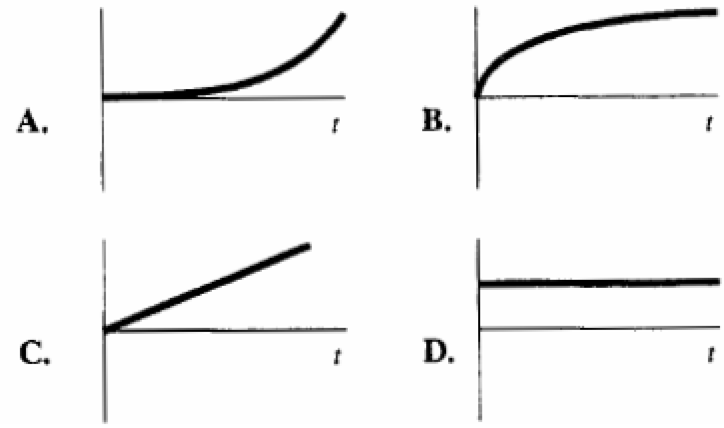
This somewhat counterintuitive result is an example of a general principle: If air resistance is negligible, then an object in free fall at the surface of the Earth has a downward acceleration of $g = 9.8\ m/s^2$. Free fall means that only the force of gravity is acting on an object.

In the following questions, consider a ball dropped from the fortieth story of a building, and consider "down" to be in the positive direction. Consider air resistance negligible unless noted otherwise.

27. How far does the object fall in the time interval from t = 0 to 4 s?
 A. 39.2 m
 B. 78.4 m
 C. 156.8 m
 D. 313.6 m

28. Which expression gives the change in velocity between t_1 = 3 s and t_2 = 4 s?
 A. $\frac{1}{2}g(t_2 - t_1)$
 B. $g(t_2 - t_1)$
 C. $\frac{1}{2}g(t_2 + t_1)$
 D. $g(t_2 + t_1)$

29. Which graph best represents velocity versus time?



30. How does the change in velocity from $t = 1$ to 2 s compare with the change in velocity from $t = 3$ to 4 s?
    A. It is less.
    B. It is the same,
    C. It is greater.
    D. It depends on the object.

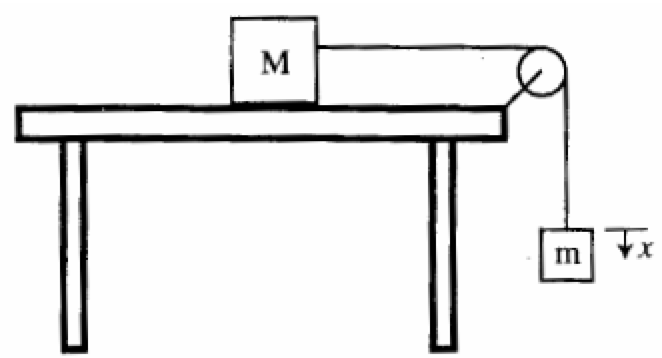
31. How does the change in height from $t = 1$ to 2 s compare with the change in height from $t = 3$ to 4 s?
    A. It is less
    B. It is the same
    C. It is greater
    D. It depends on the object

32. If an object falls a distance Δx during the first t seconds, how far does it fall during the first $3t$ seconds?
    A. $\Delta x + 3$
    B. $3\Delta x$
    C. $\Delta x + 9$
    D. $9\Delta x$

33. A Styrofoam ball of the same size as the lead ball takes a longer time to reach the ground. Which is a good explanation for this?
    A. The force of gravity does not act on the Styrofoam ball.
    B. The force of gravity on the Styrofoam ball is less than that on the lead ball.
    C. Air resistance is a significant force in this problem
    D. There is a gravitational force between the ball and the building

Passage 7 (Questions 34 -39)

We perform an experiment which involves two masses *m* and *M* connected by a string which we will consider to be massless. Mass *m* hangs over the edge of a table. The string passes over a pulley at the edge of the table and mass *M* sits on the table, such that it moves along the table without friction. (See figure.) The tension in the string is the force that the string exerts where it is connected to another object or to more string. It is generally true that the tension anywhere along the string is the same as the tension anywhere else in the string.



In this experiment the mass *m* is initially at rest and allowed to drop. Its position *x* is measured downward from its initial position. At various times, the position *x* and velocity *v* of mass *m* are measured and the results are recorded in the table which follows:

t(s)	*x*(m)	*v*(m/s)
0.0	0.00	0.0
0.2	0.01	0.1
0.4	0.04	0.2
0.6	0.09	0.3

34. Which of the following is evidence that the acceleration in uniform?
   A. The entries for *x* are nonnegative and increasing
   B. The entries for *v* are nonnegative and increasing
   C. The entries for *v* are always greater than *x*.
   D. Any interval Δv is proportional to the interval Δt.

35. Assuming that acceleration remains uniform, what is a likely entry *x* for *t*=0.9 s?
   A. 0.18 m
   B. 0.20 m
   C. 0.22 m
   D. 0.24 m

36. What are the forces on the mass *m*?
   A. The force of gravity.
   B. The force of gravity and the tension of the string.
   C. The force of gravity and the force due to mass *M*.
   D. The force of gravity, the tension of the string, and the force due to *M*.

37. What are the forces on the mass *M*?
   A. The force of gravity and the upward force of the table.
   B. The force of gravity, the upward force of the table, and the tension in the string.
   C. The force of gravity, the upward force of the table, and the force due to *m*.
   D. The force of gravity, the upward force of the table, the force due to *m*, and the tension in the string.

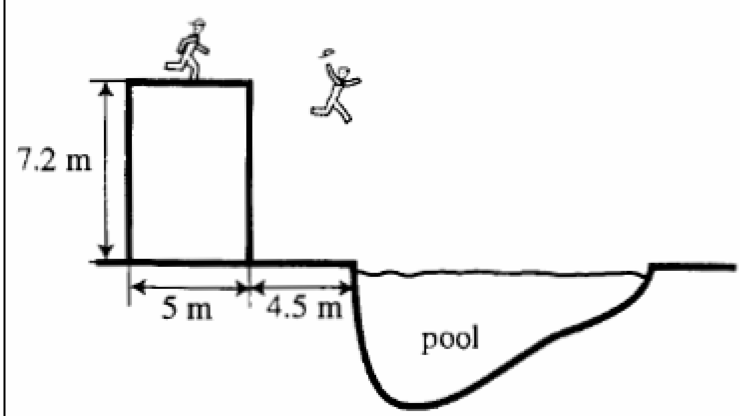
38. What is the average velocity v_{avg} for the interval of time shown in the table?
    A. 0.0 m/s
    B. 0.1 m/s
    C. 0.15 m/s
    D. 0.3 m/s

39. After the experiment has run a while, the mass *m* hits the floor and the string goes slack. But mass *M* continues going forward until it hits the pulley. After the string goes slack but before *M* hits the pulley, what are the forces on the mass *M*?
    A. There are no forces on *M*.
    B. The force of gravity.
    C. The force of gravity and the upward force of the table.
    D. The force of gravity, the upward force of the table, and a forward force.

Passage 8 (Questions 40-45)

A sport at a nearby educational institute involves running along the roof of an apartment building, jumping off the edge, and falling into the pool below. This dangerous sport involves a combination of strength of spirit, braggadocio, and inebriation.

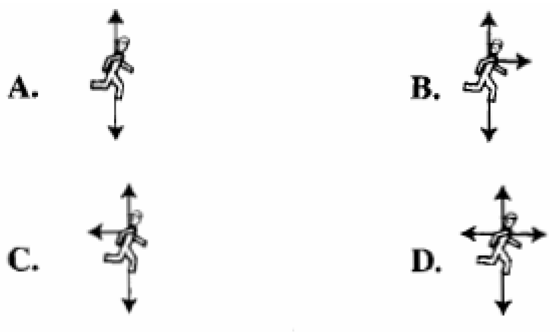
Let's say a student (50 kg) accelerates uniformly from rest at one side of the building to the jumping edge, a distance of 5 m. Just after his feet leave the building, he is traveling horizontally at a speed 5 m/s. the building is 7.2 m high, and the pool is 4.5 m from the edge of the building. Use g = 10 m/s^2.



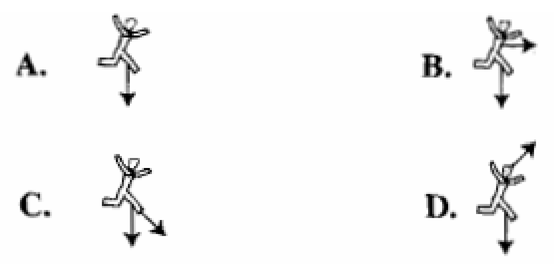
40. How much time does it take the student to accelerate as he is running along the roof?
    A. 1.00 s
    B. 1.20 s
    C. 1.44 s
    D. 2.00 s

41. How much time does it take him to fall?
    A. 1.00 s
    B. 1.20 s
    C. 1.44 s
    D. 2.00 s

42. Which diagram best represents the force diagram for the student while he is on the roof?



43. Which diagram best represents the force diagram for the student while he is in the air?



44. Where does he land?
    A. 2.5 meters from the edge of the building, that is, on the pavement.
    B. 4.5 meters from the edge of the building, that is, on the edge of the pool.
    C. 5.0 meters from the edge of the building, that is, in the pool.
    D. 6.0 meters from the edge of the building, that is, in the pool.

45. What is his horizontal velocity just before he lands?
    A. 0 m/s
    B. 5 m/s
    C. 12 m/s
    D. 13 m/s

Passage 9 (Questions 46-49)

When a massive star uses up its nuclear fuel, there is no longer enough heat to hold up its core against gravitational forces, and the core collapses. The result in an explosion, called a supernova, which leaves behind a very dense core, called a neuron star.

A neutron star is composed mainly of neutrons. It has approximately the mass of the Sun, but the radius is about 14 km, that is, 50,000 times smaller than the Sun's. the structure inside a neutron star is different from anything known on Earth, and the gravity on the surface is strong enough to crush any ordinary material. The only thing which creates a stronger gravitational field is a black hole.

Away from the surface, the tidal forces near a neutron star are nevertheless prodigious. A man falling toward a neutron star would be stretched out as he fell. He would be killed when he was about 2000 km away, and as he got closer he would be drawn as thin as a wire. Finally he would land on the surface, creating a shower of X-rays.

For these problems you may want to use the following:

$G = 6.67 \times 10^{-11}\ \mathrm{Nm^2/kg^2}$

$M_{\mathrm{sun}} = 2.0 \times 10^{30}$ kg

$V_{\mathrm{sphere}} = \frac{4}{3}\pi r^3$ (volume of a sphere)

$A_{\mathrm{sphere}} = 4\pi r^2$ (surface area of a sphere)

$A_{\mathrm{circle}} = \pi r^2$ (area of a circle)

46. What is the approximate density of a neutron star?
    A. 2×10^{17} kg/m^3
    B. 8×10^{20} kg/m^3
    C. 1×10^{24} kg/m^3
    D. 1×10^{27} kg/m^3

47. How does the acceleration due to gravity at the surface of a neutron star compare with that near the surface of the Sun?
    A. $\sqrt{50{,}000}$ times stronger.
    B. 50,000 times stronger.
    C. $(50{,}000)^2$ times stronger.
    D. $(50{,}000)^3$ times stronger.

48. The Earth is 1.5×10^{11} meters away from the Sun. If there were a planet of the same mass which was 1.5×10^{11} meters away from a neutron star, how would the neutron star's gravitational pull on that planet compare with the Sun's pull on the Earth?
    A. It would be the same.
    B. It would be 50,000 times stronger.
    C. It would be $50{,}000)^2$ time stronger.
    D. It would be 1.5×10^{11} / 14 times stronger.

49. What is the best explanation for the stretching of an object in free fall as it approaches a neutron star?
    A. The density of the neutron star is huge.
    B. The parts of an object which are nearer the neutron star are pulled more strongly than the parts which farther away from the star.
    C. The strong surface gravity is due to the fact that surface gravity varies inversely as the radius.
    D. The strong surface gravity is due to the fact that surface gravity varies inversely as the square of the radius.

Passage 10 (Questions 50- 54)

Consider an object sitting on a scale at the surface of the Earth. The scale reading is the magnitude of the normal force which the scale exerts on the object. To a first approximation, there is force balance, and the magnitude of the scale's force is the magnitude of the gravitational force:

$$F_{grav} = \frac{GM_{Earth}m}{R^2_{Earth}}$$

where G is Newton's constant, M_{earth} is the mass of the Earth, and R_{earth} is the radius of the Earth. The simple result is that the force of gravity, and the reading of the scale, is proportional to the mass:

$$F_{grav} = mg\,,$$

where g has the value $GM_{earth}/R_{earth}^2 = 9.8\ m/s^2$. We have made several idealizations, however, and if we want to calculate the scale reading, we need to be more careful.

For example, we have ignored the rotation of the Earth. Consider a man standing on a scale at the equator. Because he is moving in a circle, there is a centripetal acceleration. The result is that the scale will not give a reading equal to the force of gravity (equation [1]).

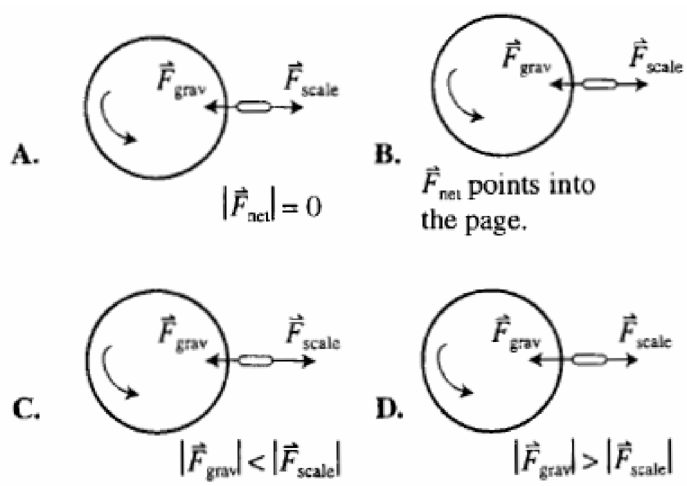
We have also assumed that the Earth is a perfect sphere. Because it is rotating, the distance from the center of the Earth to the equator is greater than the distance from center to pole by about 0.1%.

A third effect we have ignored is that the Earth has local irregularities which make it necessary to measure g in the local laboratory, if we need an exact value of the effective acceleration due to gravity.

50. For a man standing at the equator of a rotating Earth, which expression gives the best expression of his velocity? (Let T_{day} be the time of one rotation, 1 day.)
   A. R_{earth}/T_{day}
   B. $2\pi R_{earth}/T_{day}$
   C. gT_{day}
   D. $2\pi gT_{day}$

51. If we know the period of the man's motion, and we want to calculate the centripetal force on him, w hat is t he minimum number of other data that we need?
   A. 1: the radius of the Earth.
   B. 2: the radius of the Earth and the velocity of the man.
   C. 2: the radius of the Earth and the mass of the man.
   D. 3: the radius of the Earth, the velocity of the man, and the mass of the man.

52. Which is the best force diagram for a man standing at the equator of a rotating Earth?

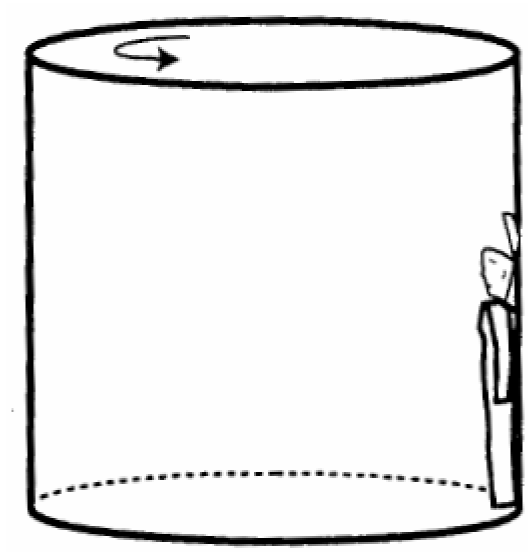


53. If the man at the equator stood on a scale, how would the scale read compared to the scale reading for an identical man standing at the equator of a non-rotating Earth?
    A. It would read less than on a non-rotation Earth.
    B. It would read the same as on a non-rotating Earth.
    C. It would read greater than on a non-rotating Earth.
    D. It would depend on where the man is.

54. If two identical men stood on scales at the South Pole and at the equator of an Earth identical to this one but non-rotating, how would the reading of the polar scale compare to the equatorial one?
    A. It would be less.
    B. It would be the same.
    C. It would be greater.
    D. There is not enough information to answer this question.

Passage 11 (Questions 55- 60)

The Drum of Discomfort is an amusement park ride which consists of a large vertical hollow cylinder which turns on its axis. A person of mass M enters the drum (inside-radius R) while the drum is still and stands against the wall. The drum begins to turn, until it achieves uniform rotation with period T and the rider feels as if some force is pushing him against the wall (see figure). Then the floor drops down, so there is nothing touching the bottoms of the rider's shoes.



Assume the coefficient of friction between the rider's clothes and the surface of the drum is μ.

55. During uniform rotation, after the floor drops, what are the forces acting on a rider, besides gravity acting down and a force acting up?
    A. There is a force pointing inward.
    B. There is a force pointing inward and a force pointing in the same direction the rider is moving
    C. There is a force pointing outward.
    D. There is a force pointing outward and a force pointing in the same direction the rider is moving

56. After the floor drops, what force provides the centripetal force?
    A. The normal force.
    B. Friction.
    C. Gravitation
    D. Tension

57. After the floor drops, which direction does the acceleration vector point?
    A. Toward the center of rotation.
    B. Away from the center of rotation.
    C. In the direction of the rider is moving.
    D. The acceleration is zero.

58. Which gives an expression for the speed v the rider is going?
    A. $R/2\pi T$
    B. R/T
    C. $2\pi R/T$
    D. $2\pi T/R$

59. What is the magnitude of the upward force on the rider?
    A. Mg
    B. μMg
    C. Mv^2/r
    D. $\mu Mv^2/r$

60. What values of μ assure that the rider will not slide down when the floor drops?
    A. μ must be less than v^2/Rg.
    B. μ must be greater than v^2/Rg.
    C. μ must be less than Rg/v^2 .
    D. μ must be greater than Rg/v^2 .

Passage 12 (Questions 61-66)

Most physical situations are quite complicated, involving a number of forces or interactions even in the simplest of cases. Much of the praxis of physics is breaking a problem into parts, treating some parts exactly and ignoring other parts. Once we have solved the idealized problem, we can use the solution to evaluate the appropriateness of the idealizing assumptions.

A simple example of this is the analysis of a tennis ball falling from a height at the surface of the Earth. The ball consists of many atoms, connected by chemical forces. In addition to the chemical forces, each atom is pulled by all the pieces of the Earth. the first idealization we make is that we can treat the ball as a point mass located at its center and the Earth as a point mass located at its center. Second, we ignore the gradient of the gravitational field, so that allows us to approximate the force of gravitation on the ball as $F_{grav} = mg$, where $g \approx 9.8$ m/s^2 is a constant.

The third effect we generally ignore is air resistance. If we ignore air resistance, we can calculate the idealized maximum velocity of the falling ball and then calculate the force of air drag. This is given by

$$F_{drag} \approx C\rho A v^2, \qquad (1)$$

where C (=0.2) is a constant, ρ (=1.3 kg/m^3) is the density of air, A is the cross-sectional area of the ball, and v is its velocity relative to the air. If the air resistance is small, then we were justified in ignoring it.

If air resistance is important, it is possible that we can still do the problem. If the ball falls far enough for there to be a force balance $F_{net} = 0$, then we can use equation (1) to solve the problem. (Actually we can only require that F_{net} be small compared to the other forces in the problem.)

For the following problems, consider a ball of radius 0.03 m and mass 0.05 kg which is tossed upward at initial velocity 3 m/s.

61. If there were no air, to what idealized height would the ball travel?
    A. 0.46 m
    B. 0.92 m
    C. 1.84 m
    D. 176.4 m

62. What is the initial drag force on the ball?
    A. 3×10^{-4} N
    B. 7×10^{-3} N
    C. 0.7 N
    D. 50 N

63. If we are going to ignore air resistance, the drag force must be small compared to
    A. The normal force.
    B. The centripetal force.
    C. The gravitational force.
    D. The frictional force.

64. We have idealized the gravitational field as being uniform. If we remove that idealization, what happens to the force of gravity as the ball travels toward the top of its flight?
    A. The force of gravity decreases.
    B. The force of gravity increases.
    C. The force of gravity decreases, then disappears at the top.
    D. The force of gravity decreases, then increases.

65. In the idealized problem, the ball attains a certain maximum height and afterwards attains a final velocity just before it reaches the ground. If air resistance is included,
   A. The height is less, and the terminal velocity is less.
   B. The height is less, but the terminal velocity is greater.
   C. The height is greater, but the terminal velocity is less.
   D. The height is greater, and the terminal velocity is greater.

66. Cats falling down from large heights often survive the fall. In fact, it has been found that a cat falling from a building at very great height (e.g., ten stories) has a better chance of surviving than a cat falling from a lesser height (five stories). Which, if true, could best explain this?
   A. The air is more dense near the ground.
   B. The force of gravity on the cat is greater near the ground.
   C. Cats falling for a while tend to stretch out their legs.
   D. Greater velocity leads to a greater force of drag.

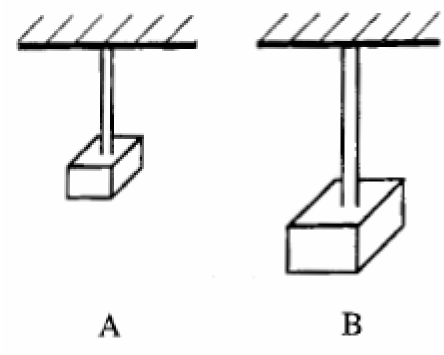
Passage 13 (Questions 67-71)

Engineers often make scale models of structures they plan to build in order to test function and stability. Sometimes, however, structures fail even when the models function, so engineers have developed extensive theory in order to determine how to build proper scale models and extrapolate reliable results from them.

At first we might assume that a model made of the same material as the intended final structure with each dimension scaled by a single factor will accurately reproduce the behaviour of the final structure. That this is not so was known in antiquity by tragic observation, and it was first explained by Galileo around AD 1600. We will not present his detailed argument but will sketch some of the conclusions.

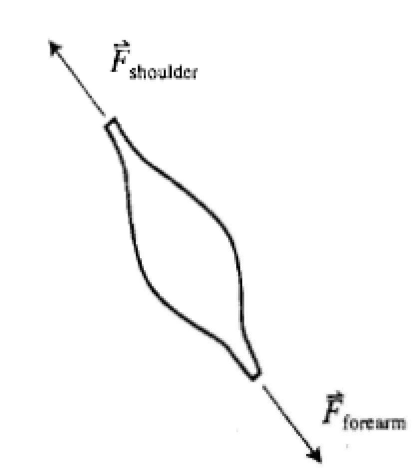
To summarize Galileo's conclusion on this point, when the linear dimensions of a structure are all increased by a factor, the load across any surface increases by the cube of the factor, whereas the strength, or the maximum force the structure can hold across any surface increases by the square of that factor. Therefore, as a structure gets larger, it tends to become unstable, more susceptible to failure.

To illustrate the point, let's consider a block of metal connected to a cylinder, which has much greater length than its diameter and is connected to the ceiling (part A in figure). The *stress* in the cylinder is the force per area across a cross section. Each material has a threshold stress, such that stress larger than the threshold causes the material to fail. If all the linear dimensions are increased by a factor (part B in figure), then the volume of the block increases by the cube of the factor, as well as the mass and weight of the block. The cross-sectional area of the cylinder increases by the square of the factor, so the stress increases as the factor itself.



This is the simplest example of the subtlety involved in model building.

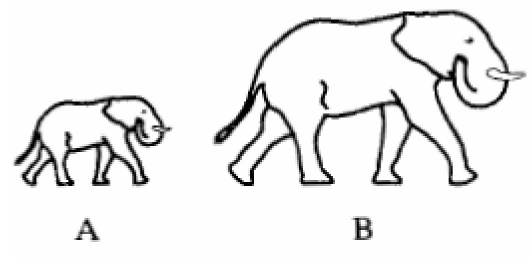
67. The figure below depicts a human biceps, which when flexed, has a cross-sectional area at its center of 5 x 10^{-3} m^2 and cross-sectional area at the forearm of 5 x 10^{-5} m^2. If the force exerted at the forearm is F_0, what is the force exerted at the shoulder?



A. $F_0/100$
B. F_0
C. 100 F_0
D. 10^4 F_0

68. Referring to the previous question, if the stress at the center of the biceps is 10^5 Pa, what is the stress at the forearm?
A. 10^3 Pa
B. 10^5 Pa
C. 10^7 Pa
D. 10^9 Pa

69. The figure below shows two elephant statues which are the same shape, both made of plaster of paris. Statue B has twice the linear dimension of statue A. if statue A weighs 40 N, how much does statue B weigh?



A. 48 N
B. 80 N
C. 160 N
D. 320 N

70. In the previous question, how does the pressure (stress) exerted by the right front foot of statue B compare with the pressure exerted by the corresponding foot of statue A?
A. It would be the same.
B. It would be twice as large.
C. It would be four times as large.
D. It would be eight times as large.

71. A lantern is hanging from a cable of negligible mass. The cable breaks when the weight of the lantern exceeds W_{max}. What would be the breaking weight for a similar cable (same material, same cross section) which was 10 times together?
A. $W_{max}/100$
B. $W_{max}/10$
C. W_{max}
D. $10W_{max}$

Passage 14 (Questions 72- 77)

A rocker engine operates on the principle that hot gas is expelled backwards through a nozzle in order to produce a thrust on the ship in the opposite direction. Since momentum is conserved in this operation, we can derive the result that the effective force on the ship is

$$F_{effective} = Mu,$$

where M is the mass expulsion rate, and u is the exhaust velocity relative to the ship. Thus it is important for both M and u to be high. The exhaust velocity varies as the square root of the ratio of the temperature of the combustion chamber and the molecular mass of the exhaust.

In conventional rocket engine design, large fuel tanks carry liquid hydrogen and oxygen, and these react by chemical combustion to yield water vapour. The water vapour due to its high temperature, shoots out of the nozzle, and the ship is thrust forward.

In an experiment engine design, nuclear fission of uranium is used to hear a supply of hydrogen to high temperature (around 2200 K). The hydrogen is then expelled through a nozzle at 1.0 x 10^4 m/s, about twice the exhaust velocity as that for conventional rockets. One major engineering problem involves the heat exchange between the hydrogen gas and the site where the nuclear reaction takes place. Engineers are improving the design so that the hydrogen is heated at a faster rate than it is in current design.

72. When a rocket ship expels gas in order to produce a thrust, this is an example of
    A. The first law of motion.
    B. The second law of motion.
    C. The third law of motion.
    D. The law of universal gravitation.

73. Could neon gas work instead of hydrogen in the design of the nuclear engine?
    A. No, since neon is not a product of uranium fission.
    B. No, since neon is an inert gas.
    C. Yes, but the engine would not be as efficient because of exhaust velocity.
    D. Yes, it would work approximately as well.

74. What, according to the passage, is a disadvantage of nuclear engines compare to conventional engines?
    A. The molecular mass of the exhaust is too low.
    B. The molecular mass of the exhaust is too high.
    C. Some of the energy is lost as heat.
    D. The mass expulsion rate is too low.

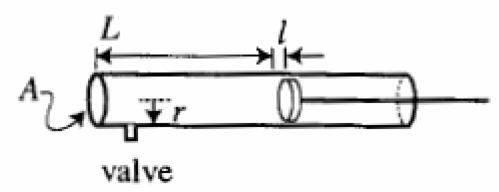
75. A rocket ship is going forward at 2000 m/s and fires its engines in order to speed up but not turn. If the absolute velocity of the exhaust gases is 3000 m/s going backwards, what is the exhaust velocity u relative to the ship?
    A. 1000 m/s
    B. 2000 m/s
    C. 3000 m/s
    D. 5000 m/s

76. We can model a rocket and its exhaust with two carts sitting on a level, frictionless one-dimensional track. The large cart (rocket) has a mass 10 kg, and the small car (exhaust gas), 0.1 kg. There is a small explosive between them. At a certain time the explosive goes off and the two carts go flying apart. The less massive cart recoils with velocity 20 m/s. the explosion is over in about 0.2s. what is the final velocity of the larger mass?
    A. 0.2 m/s
    B. 1.0 m/s
    C. 20 m/s
    D. 2000 m/s

77. In the previous question, what is a reasonable estimate for the force which is exerted on the ship during the explosion?
    A. 0.4 N
    B. 10 N
    C. 40 N
    D. 1000 N

Passage 15 (Questions 78-84)

In a certain experiment, a piston chamber is used as part of a primitive engine. The apparatus consists of a pipe closed at one end with a piston at the other end. A valve in the cylinder allows fuel gases to be introduced or waste gases to be expelled.



In the operation of this engine, hydrogen and oxygen are introduced in a 2:1 ratio (in order to ensure complete combustion) at ambient temperature T_{amb} and atmospheric pressure P_{amt}. The following reaction is ignited

$$2H_{2\,(g)} + O_2 \rightarrow 2H_2O_{(g)},$$

with a heat of reaction

$$\Delta H_{rea} = -4.8 \times 10^5 \text{ J/mol}.$$

The pressure rises to P_{burn}.

Next the piston slowly moves back a distance l, from which the engine derives useful work. The distance l is short enough that the pressure and temperature inside the chamber remain roughly constant.

The waste gases are then expelled, and the piston is restored to its original position.

The radius of the cylinder is r, and the cross-sectional area is A. the length of the cylinder before the piston moves back is L, which is much larger than l. The number of moles of oxygen introduced is n.

78. After the combustion occurs, why does the pressure go up?
    A. There are more gas particles on the left side of the reaction.
    B. The temperature rises considerably.
    C. The reaction is spontaneous.
    D. The heat of reaction is negative.

79. Which expression expresses the efficiency of the engine?
    A. $\frac{2}{3}\frac{P_{burn}Al}{n\Delta H_{rea}}$
    B. $\frac{2}{3}\frac{P_{burn}AL}{n\Delta H_{rea}}$
    C. $\frac{P_{burn}Al}{n\Delta H_{rea}}$
    D. $\frac{P_{burn}AL}{n\Delta H_{rea}}$

80. The second paragraph refers to what kind of ratio?
    A. Mass
    B. Volume
    C. Neutron
    D. Temperature

81. What would happen if the ratio in the second paragraph were not 2:1?
    A. The heat of reaction would be less than 4.8 x 10^5 J/mol.
    B. The combustion would not ignite.
    C. Some of the waste gas would be intermediate products of incomplete combustion.
    D. Some of the waste gas would be oxygen or hydrogen.

82. If the reaction shown were performed in a closed chamber isothermally at 500°C, what would happen to the pressure?
    A. The pressure would decrease.
    B. The pressure would stay the same.
    C. The pressure would increase.
    D. There is not enough information to solve this problem.

83. Which is an expression giving the number of moles of oxygen introduced in the chamber?
    A. $\frac{1}{3}\frac{P_{atm}AL}{RT_{amb}}$
    B. $\frac{1}{2}\frac{P_{atm}AL}{RT_{amb}}$
    C. $\frac{2}{3}\frac{P_{atm}AL}{RT_{amb}}$
    D. $\frac{P_{atm}AL}{RT_{amb}}$

84. What would be the consequence of making *l* larger? During the piston movement,
    A. Pressure in the chamber would decrease, and temperature would decrease.
    B. Pressure in the chamber would decrease, and temperature would increase.
    C. Pressure in the chamber would increase, and temperature would decrease.
    D. Pressure in the chamber would increase, and temperature would increase.

Passage 16 (Questions 85-93)

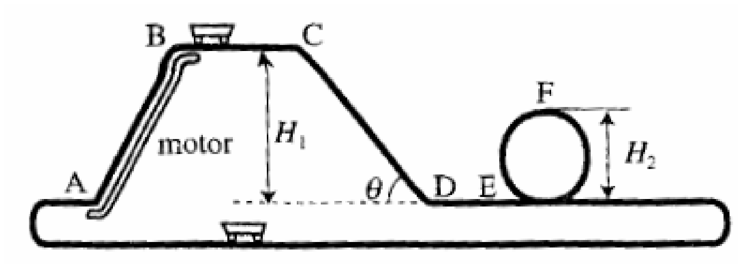
People began to make roller coasters around the early 1900s. These early roller coasters were made of wood, and people learned how to construct them using the principles of physics and by a certain amount of experimentation.

Beginning in the 1980s, constructers of roller coasters began to use computers to design them. In this way they were able to create a great many designs and simulate them, thus finding a roller coaster's weakest points and determining the cost of making them fail-safe. This, and the practice of making them of steel, made the new roller coasters larger, safer, and more fun.

Nevertheless, a fair amount of knowledge about a roller coaster can be learned by applying simple physics without the aid of a computer. For the most part, the two forces acting on the car are gravity and the normal force, for we will ignore the force of friction during the ride. A force due to a motor carries the car to the top of the first hill. Finally there is a frictional force due to rubber bumpers pressing against the car which serve to stop it at the end of the ride so that other riders can get on.

The feeling a rider experiences in the car is related to the force exerted by the car's seat on his body perpendicular (normal) to the car's motion. This is expressed as a number of g's, where g is the acceleration due to gravity. For instance, if the rider (mass m) experiences a force $2mg$, then he is said to experience $2g$'s.

Consider the figure below, a very simple roller coaster, in answering the following questions. A motor brings the car from point A to B, where it has very little velocity at a height H_1 above the ground. The slope of the first hill is an angle θ from the horizontal. The loop is a circle of whose highest point is H_2 above the ground. The mass of the car is M. The velocity of the car at point F is v_F.



85. What is the kinetic energy of the car at point E?
    A. $MgH_1 \cos\theta$
    B. $MgH_1 \sin\theta$
    C. MgH_1
    D. 2 MgH_1

86. What is the velocity of the car at point E?
    A. $\sqrt{\dfrac{gH_1}{2}}$
    B. $\sqrt{gH_1}$
    C. $\sqrt{2gH_1}$
    D. $\sqrt{2gH_1 \cos\theta}$

87. What is the velocity of the car at point F, v_F?
    A. $\sqrt{\frac{1}{2}g(H_1 - H_2)}$
    B. $\sqrt{g(H_1 - H_2)}$
    C. $\sqrt{2g(H_1 - H_2)}$
    D. $\sqrt{g(H_1 + H_2)}$

88. What is the work done by the normal force from point C to point D?
    A. 0
    B. $-MgH_1 \sin\theta$
    C. $MgH_1 \cos\theta$
    D. $MgH_1 \sin\theta$

89. How many forces are acting on the car at point F?
    A. One, the force of gravity down.
    B. Three, the force of gravity down, the normal force down, and a centripetal force toward the center of the circle.
    C. Three, the force of gravity down, the normal force down, and a force forward.
    D. None of the above.

90. What force pulls the blood to the rider's feet when the car is at point F?
    A. The centripetal force.
    B. The force of gravity.
    C. The normal force.
    D. None of the above.

91. What expression best gives the normal force on the car at point F?
    A. $\dfrac{Mv_F^{\ 2}}{H_2} - Mg$
    B. $\dfrac{Mv_F^{\ 2}}{H_2} + Mg$
    C. $\dfrac{2Mv_F^{\ 2}}{H_2} - Mg$
    D. $\dfrac{2Mv_F^{\ 2}}{H_2} + Mg$

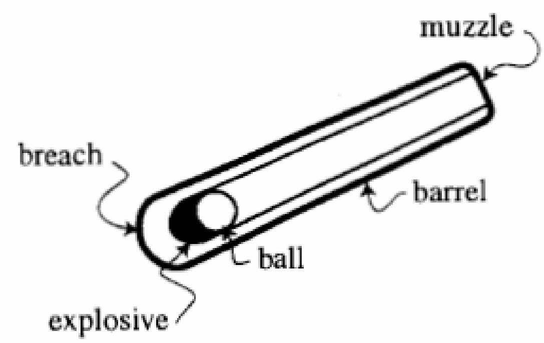
92. When it rains, the park operators run the ride with fewer people in the cars. Which of the following is a good explanation of why this is?
    A. The rain reduces the friction on the tracks and makes the cars go faster.
    B. The rain reduces the coefficient of static friction between the bumpers and the car.
    C. The rain reduces the coefficient of kinetic friction between the bumpers and the car.
    D. The rain decreases the efficiency of the motor.

93. Which of the following best describes the energy flow in this ride?
    A. Electrical to potential and kinetic to heat.
    B. Electrical to kinetic to electrical, in a circuit.
    C. Electrical to kinetic to potential.
    D. Electrical to heat to potential.

Passage 17 (Questions 94-99)

A cannon is a device for imparting a large velocity to a mass of iron, generally for the purpose of warfare. Over the centuries, the manufacture of cannons has taken many forms, but the basic construction has remained the same.

A cylinder (or *barrel*) is a closed at one end (the *breech*) is placed in the cylinder at the breech, and a ball is placed in the cylinder on top of the charge. The explosive is ignited and the reaction produces hot gases which increase the pressure. Thus the gases push the ball along the cylinder out the muzzle at great velocity.



Beginning in the 1500s, gunners began using large grained explosive in order to decrease the rate of burning. Faster burning charge creates a large pressure very quickly, thus creating stress on the cannon and creating a risk of failure. The slower burning charge ensures that the pressure behind the ball stays more nearly constant as the ball travels the length of the barrel.

For the following questions, consider a cannon which is 2.3 meters long with a bore (hole) of radius 5 centimeters. Assume the pressure inside the cannon after the explosive has been set off is constant. While the ball is in the cannon, the forces due to the gases are so much greater than the force of gravity that the force of gravity can be ignored.

94. What additional piece of information would be sufficient to allow the calculation of the kinetic energy of the ball upon leaving the cannon?
    A. The mass of the cannonball.
    B. The final velocity of the cannonball.
    C. The force of the cannonball experiences in the barrel.
    D. None of the above.

95. What additional piece of information would be sufficient to allow the calculation of the pressure in the barrel while the cannonball is still inside?
    A. The temperature of the gas in the barrel.
    B. The final velocity of the cannonball.
    C. The force the cannonball experiences in the barrel.
    D. None of the above.

96. Which of the following would best explain why a large-grained charge would burn more slowly than a small-grained charge?
    A. The rate of reaction depends on the surface area.
    B. The rate of reaction depends on the concentration of reactants.
    C. The rate of reaction depends on the temperature of reactants.
    D. The activation energy is reduced for smaller-grained charge.

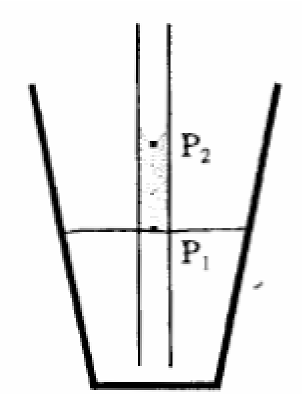
97. Which of the following is necessarily true?
    A. The entropy change during burning is zero.
    B. The free energy change during burning is negative.
    C. The free energy change during burning is zero.
    D. The free energy change during burning is positive.

98. Which of the following best describes the energy flow in the passage?
    A. Chemical to kinetic to heat.
    B. Chemical to heat to kinetic.
    C. Chemical to potential to heat.
    D. Chemical to potential to kinetic.

99. For this question, assume the cannon points straight up, and assume we know the velocity of the cannonball when it leaves the muzzle of the cannon. What additional piece of information would be sufficient to allow the calculation of the height to which the cannonball would travel?
    A. The mass of the cannonball.
    B. The kinetic energy of the ball upon just leaving the barrel.
    C. The force the cannonball experiences in the barrel.
    D. No more information is needed.

Passage 18 (Questions 100-105)

When we place a straw (a hollow cylindrical tube) in water, the water inside the straw rises above the surface level outside and a meniscus (curvature of the surface) forms. Consider the column of water in the straw from the height of the water outside the straw to the top of the column. (See figure, where the column is shown shaded.) Let P_1 be a point in the straw at the bottom of the column and let P_2 be a point inside the water column at the top.



The force due to surface tension for a maximally stretched surface is given by $F_{surf} = \gamma L$, where γ is the coefficient of surface tension (which depends only on the substance) and L is the length of the line of contact between an object and the fluid. For this problem use the following:

ρ = density of water
γ = surface tension of water
r = radius of the straw
h = height of the column
P_{atm} = atmospheric pressure
g = acceleration due to gravity

100. Which pressure is greater, the pressure at P_1 or at P_2?
   A. Pressure at P_1 is greater than at P_2 by the term ρgh.
   B. Pressure at P_1 and at P_2 are both P_{atm}.
   C. Pressure at P_1 and P_2 are the same but not P_{atm}.
   D. Pressure at P_2 is greater than at P_1 by the term ρgh.

101. What are the forces acting on the column?
   A. Gravity, down.
   B. Gravity, down; force due to pressure on top surface; force due to pressure on bottom surface.
   C. Gravity, down; force due to pressure on top surface; force due to pressure on bottom surface; and surface tension, up.
   D. Gravity, down; force due to pressure on top surface; force due to pressure on bottom surface; and surface tension, down.

102. What expression gives the magnitude of the force due to pressure on the top of the column?
   A. $F = \pi r^2 (P_{atm} - \rho gh)$
   B. $F = 2\pi r^2 (P_{atm} - \rho gh)$
   C. $F = \pi r^2 P_{atm}$
   D. $F = 2\pi r^2 P_{atm}$

103. What expression gives the force due to gravity on the column?
   A. $F_{grav} = r^2 hg$
   B. $F_{grav} = 2r^2 hg$
   C. $F_{grav} = \pi r^2 h\rho g$
   D. $F_{grav} = 2\pi r^2 h\rho g$

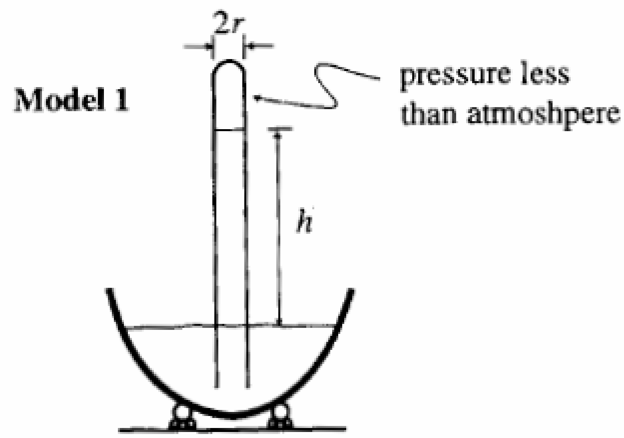
104. What expression approximates the force due to surface tension?
A. $2r\gamma$
B. $\pi r\gamma$
C. $2\pi r\gamma$
D. $2\pi r^2\gamma / h$

105. What happens if *r* decreases by a factor of 2?
A. The height *h* would stay the same.
B. The height *h* would increase by a factor of 2.
C. The height *h* would increase by a factor of 4.
D. There is not enough information to answer this question.

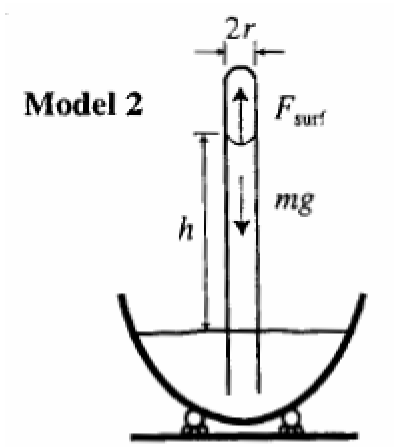
Passage 19 (Questions 106-109)

Vascular plants transport water by a passive transport system using xylem, a cell tissue which forms thin, long cylinders along branches of plants. In particular, trees use this tissue to transport water against the force of gravity to great heights.

In one model (Model 1, shown in first figure below), xylem is a tube or pipe, and water is "pulled" up by reducing the pressure at the top of the column of water in the xylem. The figure shows a tube whose bottom end is in a reservoir of water. The top end is closed and has a cavity whose pressure is less than atmospheric pressure. It turns out not to be a good model for Nature.



In another model (Model 2, shown in figure below), xylem is narrow tube which exerts a force on water by surface tension, the same force that causes water to rise in a thin straw when it is sitting in water. In this case the forces on the column of water have to be balanced, so the down-ward force of gravity is equal to the upward force of surface tension. The force of surface tension is the product of the coefficient of surface tension γ(0.072 N/m for water) and the circumference of the cylinder.



In both models the height of the column is h and the radius of the tube is r, which is about 2 x 10^{-7} m. use the estimate $P_{atm} = 10^5$ N/m^2 for atmospheric pressure. Use 10^3 kg/m^3 for the density of water and 10 m/s^2 for the acceleration of gravity.

106. What is maximum height of a column of water in xylem in Model 1?
   A. 1 meter
   B. 10 meters
   C. 20 meters
   D. 200 meters

107. How could the maximum height be increased in Model 1?
   A. Decrease the radius of the cylinder.
   B. Increase the radius of the cylinder.
   C. Increase the density of xylem.
   D. None of the above will increase the maximum height.

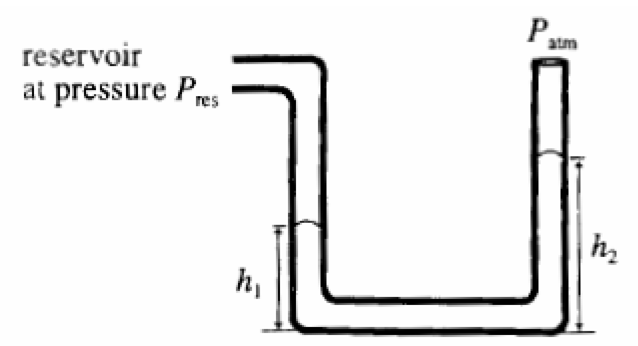
108. What is maximum height of a column of water in xylem in Model 2?
   A. 3.6 meters
   B. 36 meters
   C. 72 meters
   D. 144 meters

109. How could the maximum height be increased in Model 2?
   A. Decrease the radius of the cylinder.
   B. Increase the radius of the cylinder.
   C. Increase the density of the cylinder.
   D. None of the above will increase the maximum height.

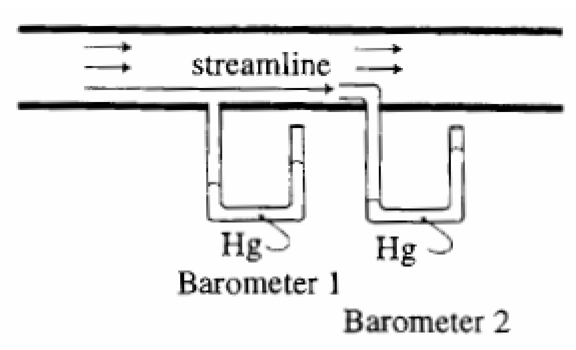
Note: The tallest trees are the redwoods, which can be as high as 100 meters.

Passage 20 (Questions 110-115)

A barometer, that is, a device that measures pressure, can be constructed from a tube which is open at both ends and shaped like a U. a fluid, like mercury, is placed inside, filling the bottom portion of the U. if the height of the mercury column at one end is greater than at the other end, then the pressure above the liquid on that end is less.

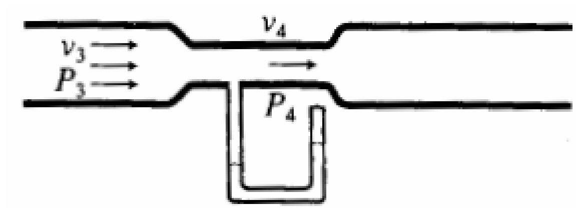


A modification of a barometer can be used to measure flow speed. Consider a pipe which carries an inviscid, incompressible fluid moving a speed v and pressure P_1 far upstream. Barometer 1 does not interrupt the flow, so it measures P_1. If Barometer 2 is placed in the flow as shown in the figure below, then the tip of the barometer forms an obstruction in the flow.



The flow just in front of the tip comes to stop at what is called a *stagnation point*. Nevertheless, we can consider the line shown in the figure, which comes to an end at the stagnation point, to be a streamline.

The figure below shows a flow with a constriction. The flow far upstream has a speed v_3, pressure P_3, and a cross-sectional area A_3. In the constriction the flow has a velocity v_4, pressure P_4, and a cross-sectional area A_4.



For the following problems, let ρ be the density of mercury.

110. In the first figure, the heights of the left and right columns of mercury are h_1 and h_2, respectively. Which expression gives the reservoir pressure P_{res}?

A. $P_{atm} - \rho g(h_2 - h_1)$

B. $P_{atm} + \rho g(h_2 - h_1)$

C. $P_{atm} - \rho g(h_2 + h_1)$

D. $P_{atm} + \rho g(h_2 + h_1)$

111. If the pressure measured by Barometer 1 in the second figure is P_1 and that measure by Barometer 2 is P_2, then what is the upstream velocity of the flow?

A. $\sqrt{\dfrac{(P_2 - P_{atm})}{2\rho}}$

B. $\sqrt{\dfrac{(P_2 - P_1)}{2\rho}}$

C. $\sqrt{\dfrac{(P_2 - P_1)}{\rho}}$

D. $\sqrt{\dfrac{2(P_2 - P_1)}{\rho}}$

112. How does the speed v_4 compare with the speed v_3?

A. The speed v_4 is less than v_3.
B. The speed v_4 is the same as v_3.
C. The speed v_4 is greater than v_3.
D. This cannot be determined from the information given.

113. How does the pressure P_4 compare with the pressure P_3?

A. The pressure P_4 is less than P_3.
B. The pressure P_4 is the same as P_3.
C. The pressure P_4 is greater than P_3.
D. This cannot be determined from the information given.

114. Suppose the fluid were replaced with an incompressible fluid that had viscosity, but v_3, P_3, A_3, and A_4 remained the same. How would the velocity, v_{4new}, in the constriction be changed from v_4?

A. The speed would be less than v_4.
B. The speed would be the same as v_4.
C. The speed would be greater than v_4.
D. This cannot be determined form the information given.

115. Again, suppose the fluid were replaced with a fluid that had viscosity, but v_3, P_3, A_3, and A_4 remained the same. How would the new pressure in the constriction be changed from P_4?

A. The new pressure would be less than P_4.
B. The new pressure would be the same as P_4.
C. The new pressure would be greater than P_4.
D. This cannot be determined form the information given.

Passage 21 (Questions 116-121)

When a guitar string is plucked, there are many frequencies of sound which are emitted. The lowest frequency is the note we associate with the string, while the mix of other frequencies gives the sound its *timbre*, or sound quality. The lowest frequency is the *fundamental*, while the higher frequencies make up the *harmonic series*. The next lowest frequency is the second harmonic; the next to lowest, the third harmonic, and so on. The timbre depends on the material of the string (steel or plastic or catgut), on the way it is plucked (middle or at the end), and on the sounding board.

Sometimes some of the frequencies may be suppressed, for example, by lightly holding a finger at a point along the string to force a node there. This is not the same as fretting the string, which involves holding the string all the way down to the neck in order to effectively change the length of the string.

The wave velocity is given by $v = \sqrt{T/\mu}$, where T is the tension in the string, and μ is the linear mass density, which is the product of material density and cross-sectional area.

For the following questions, consider an E string (frequency 660 Hz) which is made of steel. It has a mass of 0.66 grams for each meter of wire and has a circular cross-section of diameter 0.33 mm. the string length when strung on a guitar is 0.65 m.

Also note that the D string has a wave velocity of 382 m/s.

116. What is the velocity of a wave on the E string mentioned in paragraph 4?
A. 214.5 m/s
B. 429 m/s
C. 858 m/s
D. 1716 m/s

117. What is the frequency of the fundamental of the D string?
A. 294 Hz
B. 588 Hz
C. 882 Hz
D. 1175 Hz

118. What is the frequency of the fourth harmonic of the D string?
A. 588 Hz
B. 882 Hz
C. 1175 Hz
D. 2350 Hz

119. If the guitarist places her left finger lightly on the D string one fourth way from the neck end to the base, what is the lowest frequency that will be heard?
A. 588 Hz
B. 882 Hz
C. 1175 Hz
D. 2350 Hz

120. What is the wavelength of the sixth harmonic of the E string?
A. 0.22 m
B. 0.325 m
C. 3.25 m
D. 20.8 m

121. If we want to increase the frequency of the fundamental of a string by 3%, by how much do we want to change the tension in the string?
A. Increase it by 1.5%
B. Increase it by 3%
C. Increase it by 4.5%
D. Increase it by 6%

Passage 22 (Questions 122- 128)

The human ear can hear sounds with frequencies from 20 Hz to 20,000 Hz. Frequencies of sound higher than this are called ultrasound. Although they cannot be heard, they are used in the technique of ultrasound imaging, for example, to take the image of a fetus in the womb. The sound waves are reflected off the interface between the fetus and the surrounding fluid. in order for this to provide information, the wavelength of the sound has to be smaller than the object being observed. Otherwise the wave passes right around the object.

At the other end of the sound spectrum there are very low frequency sounds. These can be highly injurious to humans if they have sufficient intensity. The sounds can cause internal organs to vibrate and eventually rupture, tearing the connective tissue holding the organ in place. For intense low frequency sounds can be.

For the following, use 1500 m/s for the speed of sound in biological tissue. Use 343 m/s for the speed of sound in air. A mass *m* on a spring (constant *k*) has a frequency given by $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$.

122. For a sound wave of frequency 10^2 Hz in air, what is its wavelength?
A. 0.29 m
B. 0.56 m
C. 1.7 m
D. 3.4 m

123. If a doctor wanted to take the image of a fetus and wanted to resolve features of size on the order of one millimetre, what frequency sound could she use?

A. Any frequency less than about 3 x 10^5 Hz.
B. Any frequency greater than about 3 x 10^5 Hz.
C. Any frequency less than about 1.5 x 10^6 Hz.
D. Any frequency greater than about 1.5 x 10^6 Hz.

124. What period corresponds to the lowest frequency a human ear can hear?

A. 0.05 seconds
B. 0.05 meters
C. 17 seconds
D. 17 meters

125. Which best describes the flow of energy in paragraph 2?

A. Sound to potential
B. Sound to heat
C. Sound to gravitational
D. Sound to chemical and heat

126. In paragraph 2, which of the following would result in an increase in intensity?

A. An increase in frequency.
B. A decrease in frequency.
C. An increase in the mass of the internal organ.
D. None of the above.

127. Which of the following would be part of an explanation of why low frequency sounds are injurious?

A. The wavelength of the sound is smaller than the size of the organ.
B. The wavelength of the sound is larger than the size of the organ.
C. The sound is reflected by the organ.
D. The frequency of the natural oscillation of the organ is similar to that of the sound.

128. A scientist wants to model an internal organ with connective tissue as a mass on a spring. The mass of the organ is 0.5 kg, and its natural period of oscillation is 0.2 s. what would be the spring constant for the spring in the scientist's model?

A. 0.1 N/m
B. 0.8 N/m
C. 2.5 N/m
D. 490 N/m

Passage 23 (Questions 129-134)

Bats are mammals which have acquired the ability of flight and echolocation. Echolocation involves using vibrating membranes to direct a high frequency sound, with frequencies ranging from 12 kHz to 150 kHz. If the sound encounters a flying insect or obstacle which is larger than the wavelength of the sound, then a portion of the sound wave is reflected, and the bat detects it.

Beyond this basic framework, different species of bats use different strategies in echolocation. Some species emit a series of pulses, determining the distance to an object by the delay in return of the signal. Some emit a constant frequency, using the frequency of the returned sound to determine information about the velocity of the insect. Others use a sweep of frequencies, presumably to determine size information or directional information. Some emit a sound with a high harmonic content. Many use some combination of these strategies.

Several adaptations provide for better processing of the returned signal, including isolation of the detection apparatus from the emitting apparatus and specializations in the middle ear.

For the questions, use the following: The speed of sound is 343 m/s, and the Doppler-shifted frequency for a detector and emitter moving relative to each other is

$$f_{\text{det}} = \frac{v_s \pm v_{\text{det}}}{v_s \pm v_{em}} f_{em},$$

129. What frequency would a bat use to locate an insect 1 cm wide which is 10 m away?
A. Any frequency less than 34 kHz.
B. Any frequency greater than 34 kHz.
C. Any frequency less than 34 Hz.
D. Any frequency greater than 34 Hz.

130. If an insect is 3 m away, and a bat emits a pulse signal, how long is the delay in the return signal?
A. 0.009 s
B. 0.017 s
C. 0.09 s
D. 0.17 s

131. A bat is in pursuit of an insect. The bat is flying 10 m/s to the east, and the insect is flying 10 m/s to the east. If the bat emits a constant frequency sound of 30 kHz, what frequency will he detect?
A. 29 kHz
B. 30 kHz
C. 31 kHz
D. 32 KHz

132. What is a possible reason for using a sound with high harmonic content?
A. The harmonic frequency can determine the distance to an insect.
B. The harmonic frequency can stun the insect.
C. The harmonic frequency might be reflected even if the fundamental is not.
D. The harmonic frequency might be Doppler shifted even if the fundamental is not.

133. A bat is travelling west at 15 m/s, emitting a constant-frequency sound of 50 kHz. If it encounters an obstacle, such as a tree, what frequency sound does it detect?

A. 2.2 kHz
B. 48 kHz
C. 50 kHz
D. 55 kHz

134. Which is an adaptation which might aid an insect?

A. An ability to emit a sound with frequency much lower than that of a bat.
B. An ability to emit a sound with frequency about the same as that of a bat.
C. An ability to emit a sound with frequency much higher than that of a bat.
D. A secretion of an obnoxious tasting chemical.

Passage 24 (Questions 135-140)

The ear converts a serious of pressure variations, that is a sound wave, into a Fourier-analyzed signal traveling on nerves to the hearing center of the brain. In a highly idealized model of the ear, each frequency of sound wave corresponds to one neuron leading from the ear to the brain. For example, if a sound wave were to enter the ear consisting of two frequencies f_1 and f_2, then two neurons would be excited, one corresponding to f_1 and the other to f_2.

A physical ear is more complicated than this model, however, and these differences from ideal can be observed by simple experiment. For instance, if a sound wave of two very similar frequencies enters the ear, the brain hears not two frequencies but one average frequency which slowly turns on and off. The turning on and off is called *beats*, and the beat frequency is the difference between the two frequencies: $f_{beat} = f_1 - f_2$.

Another similar example involves a sound wave of two frequencies, which are not similar but have some harmonic relationship. In this case the brain sometimes hears a third tone, a *difference tone*, corresponding to the difference of the frequencies of the input: $f_3 = f_1 - f_2$.

This seemingly unfortunate phenomenon was a boon to the listeners of early phonographs. The phonographs were not really able to reproduce the lowest frequencies in the music, corresponding to the fundamental of the notes being played, although they would reproduce the harmonics. Often the ear would reconstruct the difference tone which would be t he missing fundamental, making it seem as if the phonograph reproduced sound better than it in fact did.

135. When waves of two frequencies combine to make one wave, this phenomenon is called

A. Diffraction
B. Interference
C. Beats
D. Difference tones

136. On a piano, someone plays the notes B_0 (30.87 Hz) and C_1 (32.70 Hz) simultaneously. A single note is heard beating. What is the frequency of the note which is heard to beat?

A. 0.55 Hz
B. 1.83 Hz
C. 31.79 Hz
D. 63.57 Hz

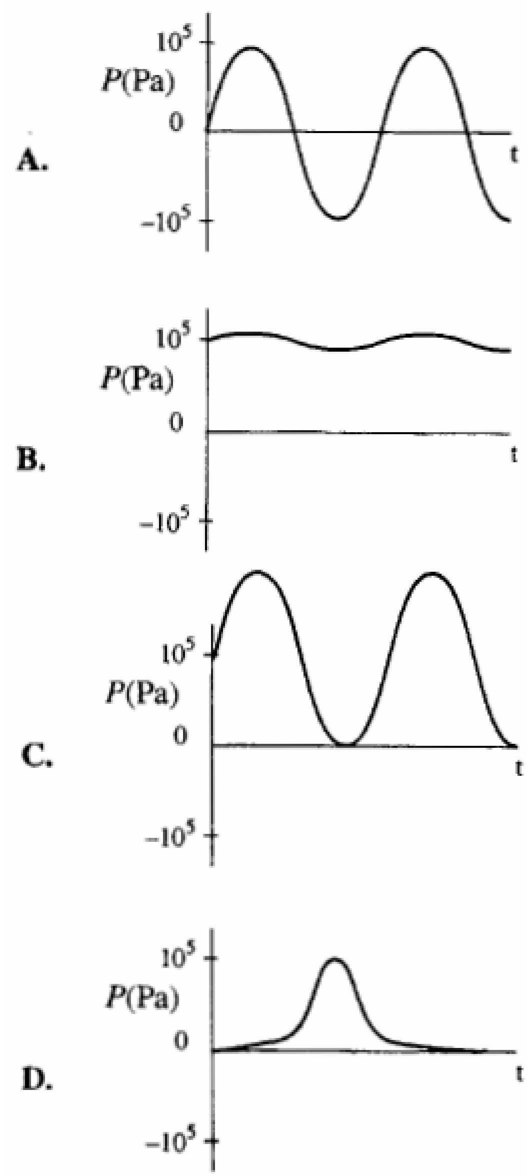
137. In the question above, how many times per second does the beat turn on and off?

A. 0.55
B. 1.83
C. 31.79
D. 63.57

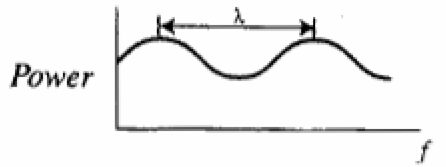
138. If a phonograph fails to reproduce the fundamental tone 110 Hz, which of the following sets of harmonics might cause the ear to reproduce it?

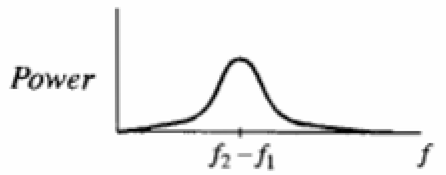
A. 27.5 Hz and 137.5 Hz
B. 55 Hz and 165 Hz
C. 220 Hz and 330 Hz
D. 220 Hz and 440 Hz

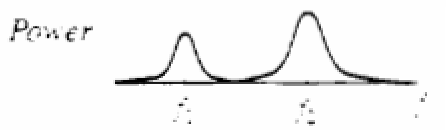
139. If the equilibrium pressure in the room is 10^5 Pa, which best represents pressure as a function of time for a sound wave of one frequency?

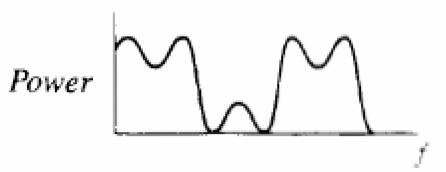


140. Which best represents a power spectrum of the sound entering the ear in paragraph 3 of the passage?

A.


B.


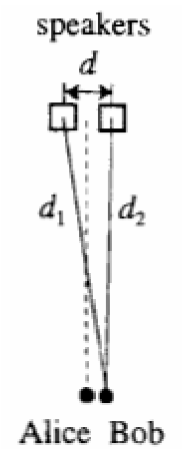
C.


D.


Passage 25 (Questions 141-146)

Alice places two stereo speakers a distance *d* apart. She sends a signal which is a sine wave of frequency *f*, so that the speakers are producing the same pure tone in phase. The sound wave in air has a wavelength λ.

She enlists her friend Bob to do an experiment. Alice sits directly in front of the speakers on the line which bisects the line segment connecting the speakers (see figure) but relatively far away from the speakers. Bob starts at the same place, but he slowly moves to the right. For him the sound gets quieter as he moves right, until he can barely hear it. Then it begins to get louder again. The figure shows Bob's position: where he first can barely hear the sound. This is the set up.



In Experiment 1, Alice and Bob keep their positions and Alice changes the frequency of the signal sent to both speakers, so that both speakers are still producing a sound in phase at the same frequency (a different frequency from the set up).

In Experiment 2, Alice changes the frequency of the second speaker slightly, but the first speaker remains at the original frequency.

The distance d is large compared to the wavelength, and it is small compared to the distance Alice and Bob sit from the speakers. The distance from Bob to the left speaker is d_1, and his distance to the right speaker is d_2.

141. Which is true concerning the set up?
 A. Alice and Bob are both at antinodes.
 B. Alice is at an antinode, and Bob is at a node.
 C. Alice is at a node, and Bob is at an antinode.
 D. Alice and Bob are both at nodes.

142. Which is the best explanation that Bob hears little sound where he sits in the set up?
 A. The sound is blocked by the speakers.
 B. Alice's body is absorbing the sound.
 C. Waves from the two speakers are out of phase and add to zero.
 D. Waves from the two speakers are in phase and add to zero

143. Which of the following is the best expression for $d_1 + d_2$?
 A. $\frac{\lambda^2}{d}$
 B. $\frac{d^2}{\lambda}$
 C. $\frac{d^2 + \lambda^2}{\lambda}$
 D. There is not enough information in the passage to answer this question.

144. Which of the following is the best expression for $d_1 - d_2$?
 A. $\frac{1}{2}d$
 B. d
 C. $2d$
 D. $\frac{1}{2}\lambda$

145. In Experiment 1, what is the best prediction for what Alice and Bob will observe?
 A. Alice will hear very little sound, and Bob will hear sound clearly.
 B. Alice will continue to hear sound, and Bob will continue to hear little.
 C. Alice will continue to hear sound, and Bob's hearing of sound depends on the chosen frequency.
 D. Nothing can be predicted, in that Alice and Bob's haring of sound depends on the chosen frequency.

146. In Experiment 2, what is the best prediction for what Alice and Bob will observe?
 A. Alice will continue to hear sound, and Bob will continue to hear little
 B. Alice will continue to hear sound, and Bob's hearing of sound depends on the chose frequency.
 C. Alice and Bob will hear a sound which grows and fades and grows.
 D. Neither Alice nor Bob will hear very much sound.

Passage 26 (Questions 147-156)

The mammalian eye is designed to collect light and focus it onto the retina. The retina consists of an array of cells, each having the ability to detect light fallins on its surface. Most of the refraction (and thus focusing) of incoming light rays takes place at the interface between air and the cornea. The lens does the finetuning, changing the focal length so the image lands exactly on the retina. The tuning is necessary since the eye must be able to bring into focus light from objects as close as 0.1 m as well as light from an infinitely distant source.

Spatial resolution is the ability of the eye to distinguish waves coming from different directions. For example, if a distant car is facing you at night with its headlights on, you can see two distinct headlights, since the light from the two headlights approaches your eye from two directions (see figure). If the car is far enough away, however, your eye lacks the resolution to distinguish the headlights, and you see only one light source.

Resolution is measured in degrees or radians. For instance, if your eye can just resolve two headlights which are 1.5 m apart on a car which is 1 km away, then the angular separation of the lights is approximately 1.5 m/1000 m = 1.5×10^{-3} radians. The resolution of your eye is 1.5×10^{-3} rad or 0.09 degrees (since 1 rad ≈ 57º) or 5 seconds of an arc. To a good approximation, the angular separation of two light sources (or features on any sort) is the ratio of spatial separation Δx to distance from the point of reference *L*. (See figure.) Thus the better the resolution the smaller the resolution angle.

Ultimately the spatial resolution of any detector, including the eye, is limited by *diffraction*, which is the spreading of waves. When waves pass through an aperture, they spread on the other side subtending an angle given by

$$\theta_{diff} = \frac{\lambda}{d}, \qquad (1)$$

where θ_{diff} is measured in radians, λ is the wavelength of the wave involved, and *d* is the diameter of the hole through which the waves must pass. Of course, diffraction is the physical limit of the resolution. The actual resolution of a detector may be much poorer than equation (1) would indicate if it is poorly designed. The human eye, when functioning properly, is essentially diffraction limited.

For the following problems use $c = 3.0 \times 10^8$ m/s. Green light has a wavelength of 520 nm in a vacuum. (1 nm = 10^{-9}m).

147. What is the frequency of green light?
   A. 64×10^{-3} Hz
   B. 160 Hz
   C. 5.8×10^{14} Hz
   D. 1.2×10^{15} Hz

148. A human eye is focused on a moth of size 0.01 m located 0.25 m away. The front to back length of the eye 0.025 m. What is the size of the image on the retina?
   A. 10^{-4} m
   B. 2.3×10^{-4} m
   C. 10^{-3} m
   D. 0.023 m

149. In question 2, what angle is subtended by the moth in the view of the eye?
   A. 2.3^o
   B. 4.6^o
   C. 15^o
   D. 30^o

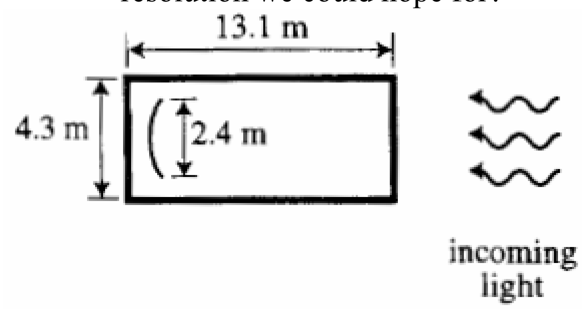
150. A certain eye does not focus correctly, being either near- or far-sighted. The front to back length of the eye is 0.025 m, but the focussing power of the resting eye is 35 diopters. What should be the approximate power of the approximate corrective lens?
   A. -5 diopters
   B. -3 diopters
   C. 3 diopters
   D. 5 diopters

151. The cornea is made of a material which has a larger index of refraction for blue light than for red light. If the eye is focusing a beam of red light onto the retina, where would the focus for a beam of blue light fall?
   A. In front of the retina.
   B. On the retina.
   C. Behind the retina.
   D. Both in front of and behind the retina.

152. An engineer is working on a camera to photograph the distant landscape in foreign countries. He has designed a camera with a lens which focuses incoming light on a detector. The camera is essentially diffraction limited, but the resolution is not good enough. Which of the following could improve the resolution?
   A. Increase the distance from the lens to the detector.
   B. Improve the lens shape.
   C. Change the material of the lens to be more transparent.
   D. Increase the size of the whole camera.

153. A Seurat painting consists of many dots of paint about 0.002 m in diameter. If you view it from a great enough distance, the dots of color appear to blend together, and you see a coherent picture. The resolution of your diffraction-limited eye is 2×10^{-4} radians. If you wanted t know how far away need you be for the dots to blur together, which paragraph in the passage gives the information to calculate this?
   A. Paragraph 3, and you must stand 2 m away.
   B. Paragraph 3, and you must stand 10 m away.
   C. Paragraph 4, and you must stand 2 m away.
   D. Paragraph 4, and you must stand 10 m away.

154. The figure shows a cross section of the Hubble Space Telescope (HST) (length 13.1 m and diameter 4.3 m). Light comes in from the right and is focused by the primary mirror (focal length 13 m). The focus is directed by a secondary mirror into detection apparatus (not shown). The perimeter of the mirror is a circle whose diameter is 2.4 m. if the HST is used for viewing galaxies in visible light, which of the following gives an estimate for the best resolution we could hope for?



A. 2×10^{-7} radians
B. 0.045 radians
C. 0.09 radians
D. 0.18 radians

155. The Hubble Space Telescope in question 8 above also has detectors for ultraviolet light. Assuming diffraction limitation, we would expect that the resolution in the ultraviolet would be
A. Not as good as that for visible light.
B. About the same as that for visible light.
C. Better than that for visible light.
D. Sometimes not as good as, sometimes better than that for visible light.

156. A cat's eye, adapted for seeing at night, has a larger pupil than a human eye and a much larger lens. The resolution for a cat's eye, however, is not better than that of a human eye, which is almost diffraction limited. Which of the following is a possible explanation for the lack of resolution in a cat's eye?
A. The larger pupil allows more light to enter the eye.
B. The larger pupil restricts the amount of directional information entering the eye.
C. The large lens introduces chromatic aberration.
D. The large lens introduces spherical aberration.

Passage 27 (Questions 157-162)

The radio waves which carry information in a standard broadcast are an example of electromagnetic radiation. These waves are a disturbance, not of a material medium, but of electric and magnetic fields. When the wave is linearly polarized, the electric field points in a direction perpendicular to the propagation of the wave, although its magnitude varies, of course, in space and time. The magnetic field points in a direction perpendicular to the wave propagation and to the electric field, and the two fields propagate in phase.

The electromagnetic radiation is generated by an antenna, which is a wire or metal rod which points perpendicular to the direction of the intended wave propagation. An alternating current is generated in the antenna, whose frequency is the same as that of the radiation to be produced. The electric field of the resulting electromagnetic radiation points along the same axis as the current.

The electric field of the electromagnetic radiation encounters electron on the receiving antenna, which is another wire or metal rod. The electric field creates a current mission and reception is to have the length of the antenna be one quarter of the wavelength of the electromagnetic wave.

For the following questions, consider a situation in which a transmitting antenna points vertically, and the receiving antenna is directly to the north. The speed of light is 3×10^8 m/s.

157. If the alternating current in the transmitting antenna has a frequency of 10^7 Hz, what would be a reasonable length for an efficient antenna, according to the
   A. 7.5 m
   B. 30 m
   C. 60 m
   D. 120 m

158. For a point between the two antennas, what is the direction of the electric field vector for the radiation?
   A. North/south.
   B. East/west.
   C. North/south or east/west.
   D. Up/down.

159. For a point between the two antennas, what is the direction of the magnetic field vector for the radiation?
   A. North/south.
   B. East/west
   C. North/south or east/west
   D. Up/down.

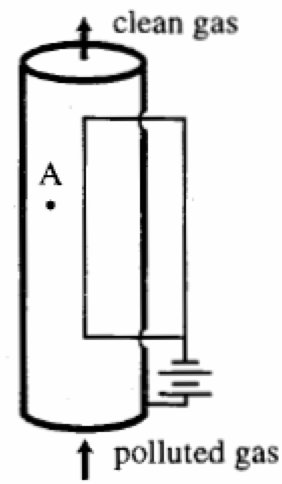
160. What would be the best orientation of the receiving antenna?
   A. North/south, that is, pointing toward the transmitting antenna.
   B. Vertical.
   C. East/west.
   D. Any orientation would suffice.

161. In the third paragraph, how does the electric field create a current of the receiving antenna?
A. The electric field changes the resistance of the antenna.
B. The electric field exerts a force on the electrons.
C. The electric field boosts the electrons to higher energy orbitals in the atoms.
D. The electric field polarizes the electrons.

162. Which of the following best describes the energy flow?
A. Electrical to electromagnetic to electrical
B. Electromagnetic to electrical to electromagnetic
C. Mechanical to electromagnetic to mechanical
D. Kinetic to electromagnetic to kinetic

Passage 28 (163-169)

An electrostatic precipitator is a device used in industry to remove pollution from exhaust gas. It consists of a long thin wire surrounded by a conducting cylinder, such that a potential about 5×10^4 volts is maintained between the negative wire and the positive cylinder. (See figure.)



The resulting electric field inside the cylinder varies inversely with the distance from the centre wire. Neutral particles of pollution are attracted to the center wire. The electric field near the wire is strong enough (greater than about 3×10^6 N/C) to ionize air, so the pollution particles are ionized negatively. They are attracted to the outer cylinder, where they collect and are eventually removed.

A typical energy requirement for such a device is about 300 Joules for each cubic meter of gas processed.

Note: The charge on an electron is -1.6×10^{-19} C. Point A is in the plane of the page.

163. If a sodium ion is at Point A, in what direction would it experience a force?
   A. Right
   B. Left
   C. Up
   D. Down

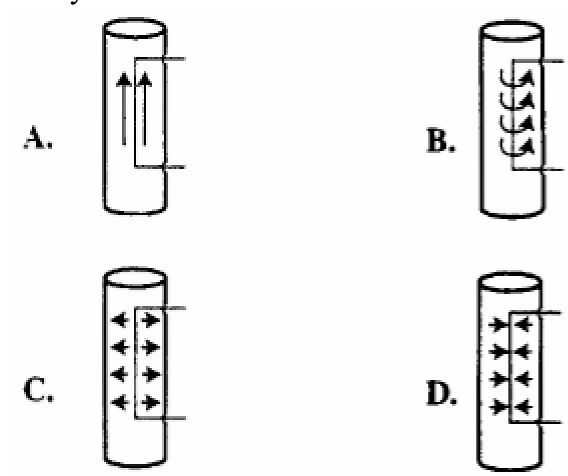
164. If a $C_{12}H_{18}O_2$ molecule is at point A, in what direction would it experience a force?
   A. Right
   B. Left
   C. Up
   D. Down

165. If a fluorine atom were ionized to form fluoride (mass 3×10^{-26} kg) near the center wire, what is the best approximation for the maximum kinetic energy it would have by the time it reached the outer cylinder?
   A. 8×10^{-31} J
   B. 1.5×10^{-23} J
   C. 10^{-20} J
   D. 8×10^{-15} J

166. If the potential maintained across the wire/cylinder were increased, how would the capacitance of the device be affected?
   A. The capacitance would decrease.
   B. The capacitance would stay the same.
   C. The capacitance would increase.
   D. The capacitance could decrease or increase depending on the gas in the cylinder.

167. If the flow rate of gas through an electrostatic precipitator is 100 m^3/s, what would be the electrical current through the device?
   A. 0 amps
   B. 10^{-2} amps
   C. 0.8 amps
   D. 3×10^4 amps

168. Which of the following best represents the electric field lines in the cylinder?



169. Which of the following is the close analogy to the attraction of neutral particles of pollutants to the center wire?
   A. The aligning of a small magnet to Earth's magnetic field.
   B. The attraction between a chloride ion and a sodium ion in a salt crystal.
   C. The Van de Waals attraction between two nitrogen molecules in air.
   D. A charged comb picking up pieces of paper.

Passage 29 (Questions 170-175)

The two dominant forces in the nucleus of an atom are the electromagnetic force, which is the repulsive force among protons, and the strong force, which is attractive among protons and neutrons. Many of the things we observe in nuclei can be explained by a balance of these forces, combined with the Pauli principle for the particles in the nucleus. For instance, most stable nuclei have somewhat more neutrons than protons, although nonmassive stable nuclei have about the same number of neutrons as protons. Nuclear physicists say that these nuclei are in a *valley of stability*, so that

$$N \geq Z,$$

where N is the number of neutrons and Z is the atomic number, and the symbol means that N is greater than or approximately equal to Z.

When the difference N-Z is strongly positive, it is likely that a nucleus will decay by β^- decay, in which a neutron converts into a proton, an electron, and an antineutrino (which rarely interacts with matter).

When N-Z is only slightly positive or even negative, then there are two likely modes of decay: β^+ decay and K-capture. In β^+ decay (also called positron decay), a proton is converted into a neutron, a positron, and a neutrino.

In K-capture, an electron from an orbital of the first shell (or K-shell, that is, the 1s orbital) combines with a nuclear proton to make a neutron and a neutrino. This often happens in nuclei in which positron decay is forbidden, for instance, because it is energetically unfavourable. K-capture is possible because there is some overlap of the first-shell orbital and the volume taken up by the nucleus, that is, the first-shell orbital has a nonzero amplitude at the center of the nucleus.

170. Which of the following represents the K-capture decay of ^{56}Ni?
   - A. $^{56}Ni \rightarrow {}^{56}Co + e^+ + v$
   - B. $^{56}Ni \rightarrow {}^{56}Cu + e^- + \overline{v}$
   - C. $^{56}Ni \rightarrow {}^{56}Co + e^- + \overline{v}$
   - D. $^{56}Ni + e^- \rightarrow {}^{56}Co + v$

171. What kind of nuclei would tend to undergo K-capture?
   - A. Nuclei with many more neutrons than protons.
   - B. Nuclei with more protons than neutrons.
   - C. Nuclei with a deficit of electrons.
   - D. Nuclei with protons in low energy orbitals.

172. Which of the following, if true, would explain why L-capture, the interaction of a nucleus with a second-shell electron, is extremely rare?
   - A. The second-shell has greater energy than the first shell.
   - B. The second-shell has a vanishing amplitude in the nucleus.
   - C. The second-shell electrons are easily removed from the atom.
   - D. The second-shell electrons cannot be converted to positrons

173. When an atom undergoes K-capture, several photons are often observed in the vicinity of the event. Which is the best explanation for this?
   A. The neutrino ionizes the surrounding atoms.
   B. The neutron decays into particles which ionizes surrounding atoms.
   C. Electrons in outer shells make transitions to lower shells.
   D. The positron interacts with an electron.

174. What happens to the difference *N*-*Z* during normal beta decay?
   A. Decreases by 2
   B. Decreases by 1
   C. Increases by 1
   D. Increases by 2

175. What happens to *N*-*Z* during the alpha decay?
   A. Decreases by 4
   B. Decreases by 2
   C. Stays the same
   D. Increases by 4