Questions and Problems

For many years I have given a course in elementary acoustics at the University of Southern California. This course is designed to acquaint music students with the basic concepts of physics and acoustics and the application of these concepts to the production and perception of music. My book, *The Acoustical Foundations of Music*, is an outgrowth of my experience in teaching this course. As part of the course requirements, the students were given problem assignments designed to furnish quantitative applications of the physical and acoustical concepts discussed in the book. It was emphasized that practice by working such problems is as important to learning physics as practice on a musical instrument is important to learning to perform music.

Now that *Acoustical Foundations* has been published in a second edition, it seems appropriate to make available a collection of questions and problems to enhance the usefulness of the book as a classroom text. To this end, I have compiled the material presented herewith. Many of the problems given below are ones that I have used in my own course, and have thus been well tested on students over a period of years. However, the remaining ones have been composed anew for this collection, and may show deficiencies. The questions likewise have been newly composed. In constructing them, I have tried to make them somewhat challenging to a student's physical intuition, and not just queries that can be answered by finding the appropriate sentence in the book. However, they also have not been tested on students, and so can undoubtedly be improved.

It is planned to expand this collection of questions and problems into a workbook to supplement *Acoustical Foundations* for classroom use. To this end any suggestions for improving this material, or for new questions or problems to be added to it, will be gratefully received.

John Backus
University of Southern California
November 1977

Chapter One
The Fundamental Physical Quantities

Questions

1-1. Name some physical quantities familiar in everyday life.

1-2. Name as many units of length as you can.

1-3. Express in simpler terms : kilomicrometer; megamillimeter; millikilometer.

1-4. Is area a vector quantity? Volume?

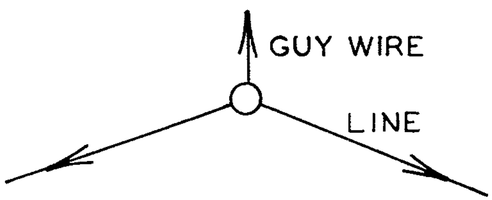
1-5. The *liter* is defined as $10^{-3}\,m^3$. Chemists use a unit called a milliliter. What cubical volume does this correspond to?

1-6. The length of the year is 365.242 solar days. Why do we have leap years? The present pattern is to omit leap year every exact century except those divisible by 400 (e.g., 1900 was not a leap year; 2000 will be). Why is this done?

1-7. An advertisement states that a certain automobile can speed up from rest to 50 miles per hour in 5 seconds. What acceleration does this correspond to? If the car were loaded with passengers, how would this affect the acceleration?

1-8. Two teams engaged in a tug-of-war are at a standstill, being evenly matched. (a) What is the resultant of the two forces exerted on the rope by the two teams? (b) One team gains a slight advantage and begins to pull the other team along the ground at a constant speed. Now what is the resultant?

1-9. When a power line turns a corner, a guy wire is used to pull on the corner pole as shown in the figure. Why is it used, and what direction should it have?



1-10. A car is going around a circular curve at a constant speed. What is the direction of the acceleration?

1-11. (a) A car is moving along a straight road at a constant speed. Diagram all the forces acting on the car. (b) The driver of the car applies the brakes. Diagram the forces for this case.

1-12. What is the weight of an astronaut in a satellite vehicle orbiting the earth? Does the astronaut have to worry about such mundane things as bumping his head on a door frame?

1-13. Express Eq. (4), p. 14, in English units, using the pound as the unit for both force and mass.

1-14. In Fig. 7, p. 18, what is the resultant of all the forces on the immersed object due to the pressure of the fluid?

1-15. Is physical work done by a person (a) in raising a bucket of water out of a well, (b) carrying it across the yard, and (c) pouring it into a tub?

1-16. The kinetic energy W in joules possessed by a mass of m kilograms moving with a velocity of v meters per second is given by

$$W = \frac{1}{2} m v^2 .$$

Can you give a reason (guided by intuition) why the velocity must be squared?

1-17. Find the wattage ratings of some home appliances.

Problems

1-1. Using the relation 1 foot = 0.3048 meters, work out the following to three significant figures:

1 inch = ______________________ centimeters

1 meter = ______________________ feet

1 mile = ______________________ kilometers

1 centimeter = ______________________ inches

1 kilometer = ______________________ miles

1 meter = ______________________ inches

1-2. Using the above results, work out the following to three significant figures:

1 square inch = ______________ square centimeters

1 cubic inch = ______________ cubic centimeters

1 square mile = ______________ square meters

1-3. Work out the following using scientific notation:

(a) $0.00000050 \times 2{,}500{,}000{,}000 \times 100{,}000{,}000{,}000$

(b) $\dfrac{2{,}500{,}000 \times 3{,}000{,}000}{0.00000015}$ (c) $\dfrac{0.000050 \times 4000 \times 0.000060}{30{,}000 \times 0.00020 \times 0.0000020}$

(d) $\dfrac{0.00028}{3{,}500{,}000 \times 20{,}000}$ (e) $\dfrac{1}{.00050 \times 200 \times 0.0000030}$

1-4. Given the radius of the earth at 4.0×10^3 miles, find: (a) the radius of the earth in feet; (b) the radius in centimeters; (c) the area of the earth in square miles; (d) the area in square feet; and (e) the area in square centimeters. Use scientific notation and *two* significant figures. (Area of a sphere = $4\pi r^2$.)

1-5. Find the following to three significant figures:

1 km/hr = ______________________ ft/sec.

1 cm/sec = ______________________ ft/min.

1 knot = ______________________ cm/sec.

60 mi/hr = ______________________ ft/sec.

1-6. If a person can walk at a speed of 8 kilometers per hour, how long would it take him to walk a distance equal to that from the earth to the sun (93×10^6 miles)? Express as hours and as years.

1-7. One pound (mass) = 0.45359237 kilograms exactly. Find the following to three significant figures:

1 kilogram = ______________________ pounds

1 ounce = ______________________ grams

1 ton = ______________________ kilograms

1-8. The gallon is defined as exactly 231 in^3. Find the number of quarts in one liter. (See Question 1-5.)

1-9. The distance from the earth to the moon, in round numbers, is 240,000 miles. How long will it take a flash of light to leave the earth, reflect from the moon, and return to the earth, if light travels at a speed of 299,793,500 meters per second? (Use scientific notation and the proper regard for significant figures.)

1-10. One newton equals how many pounds force?

1-11. The formula D = S × t is valid for consistent units of distance, speed, and time. Find a formula which will give the distance D in *feet* traveled in a time t minutes by a car going S *miles/hr.*

Two significant figures are sufficient for the following:

1-12. A motorcycle starts from rest and accelerates uniformly to a speed of 60 miles per hour in 8 seconds. Find its acceleration (a) in miles per hour second; (b) in feet per second squared; (c) in feet per hour second; and (d) in feet per second hour. (e) How fast will it be traveling 12 seconds after starting, assuming that it maintains the same acceleration?

1-13. A motorcycle is traveling 30 miles per hour. If the brakes are applied, causing it to decelerate at a rate of 8.8 feet/second squared, (a) how long will it take to stop, and (b) how many feet will it go while stopping?

1-14. A force of 10 newtons is exerted on a 20 kilogram mass initially at rest. If it acts for 12 seconds, how fast will the mass then be moving?

1-15. A force of 10 newtons acts on a 5 kilogram mass originally at rest. How long must it act to give the mass a speed of 20 meters per second?

1-16. A golf ball of mass 0.10 kilograms is struck by a club and given a speed of 80 meters per second in 0.005 seconds. Find (a) the acceleration of the ball, and (b) the force exerted on it by the club.

1-17. A ball of mass 0.20 kilogram is thrown vertically downward onto a hard floor. It strikes the floor with a speed of 20 meters per second, and rebounds upward with the same speed. If it is in contact with the floor for 0.002 seconds, find (a) its acceleration, and (b) the force exerted on it while it is in contact with the floor.

1-18. A man has a mass of 72 kilograms. (a) What is his weight on the surface of the earth? (b) What would be his weight on the moon?

1-19. What is the mass of the air in a vertical column of one square meter cross section and extending past the top of the atmosphere?

1-20. (a) At what depth under water is the pressure due to the water equal to one atmosphere? (b) What will be the total pressure at this depth? (The density of water is 1 kilogram per liter, and one atmosphere = 1.01×10^5 newtons/square meter.)

1-21. A cylindrical can contains 8 kilograms of water. If the bottom is round and 12 inches in diameter, what is the pressure on it in newtons per square meter?

1-22. If the can of Problem 1-21 is emptied of water, closed off with a lid, and the air in it evacuated, what will be the force on the lid due to atmospheric pressure?

1-23. A force of 10 newtons is exerted on a 20 kilogram mass initially at rest. It acts for 12 seconds, and moves the mass a distance of 36 meters. (a) Find the work in joules done by the force, and (b) find the power expended by the force while acting.

1-24. A man throws a ball of mass 0.6 kilograms, giving it a speed of 5 meters per second in 0.25 seconds. (a) Find the acceleration of the ball; and (b) find the force exerted on it.

1-25. (See Question 1-16.) In Problem 1-23, (a) find the speed of the mass after the force has been acting on it. (b) Using this, find the kinetic energy of the mass and see if it is the same as the work that was done by the force.

1-26. Similarly, in Problem 1-24 (a) find the kinetic energy of the ball after it has been thrown; (b) from this, find the distance over which the man exerted the force when throwing the ball; and (c) find the power expended while throwing it.

1-27. A 5 kilogram mass is raised 20.4 meters off the ground. (a) How much work is done on it? (b) It is then released so that it falls and strikes the ground. How fast is it moving when it hits? (c) For how long does it fall?

1-28. A 60 watt lamp is lit for 24 hours. (a) Find the energy expended in it in joules; and (b) find how far this energy would lift a mass of one ton.

1-29. If the energy available in one ton of water descending a distance of 1000 feet is used to light a 100 watt lamp, for how many hours will the lamp be lit?

1-30. Refer to Fig. 3(b), p. 12. If a push of 25 newtons is required to give the block a constant speed of 6 meters per second, what power in watts is being expended to keep the block in motion?

Answers to Problems

1-1. 2.54 cm; 3.28 ft; 1.61 km; 0.394 in; 0.621 mi; 39.4 in.

1-2. 6.45 cm^2; 16.4 cm^3; 2.59×10^6 m^2.

1-3. (a) 1.25×10^{14}; (b) 5×10^{19}; (c) 1; (d) 4×10^{-15}; (e) 3.3×10^6.

1-4. (a) 2.1×10^7 ft; (b) 6.4×10^8 cm; (c) 2.0×10^8 mi^2; (d) 5.6×10^{15} ft^2; (e) 5.2×10^{18} cm^2.

1-5. 0.911 ft/sec; 1.97 ft/min; 51.5 cm/sec; 88 ft/sec.

1-6. 1.9×10^7 hr; 2100 years.

1-7. 2.20 lb; 28.3 gm; 907 kg.

1-8. 1.057.

1-9. 2.57 sec.

1-10. 0.224 lb.

1-11. $D_{ft} = 88\, S_{mi/hr} \times t_{min}$.

1-12. (a) 7.5 mi/hr sec; (b) 11 ft/sec^2; (c) 4.0×10^4 ft/hr sec; (d) 4.0×10^4 ft/sec hr; (e) 90 mi/hr or 132 ft/sec.

1-13. (a) 5 sec.; (b) 110 ft.

1-14. 6 m/sec.

1-15. 10 sec.

1-16. (a) 1.6×10^4 m/sec^2; (b) 1.6×10^3 N.

1-17. (a) 2×10^4 m/sec^2; (b) 4×10^3 N.

1-18. 706 N; 118 N.

1-19. 1.0×10^4 kg.

1-20. (a) 10 m; (b) 2.0×10^5 N/m^2.

1-21. 1.1×10^3 N/m^2.

1-22. 7.4×10^3 N.

1-23. (a) 360 J; (b) 30 W.

1-24. (a) 20 m/sec^2; (b) 12 N.

1-25. (a) 6 m/sec; (b) 360 J.

1-26. (a) 7.5 J; (b) 0.63 m; (c) 30 W.

1-27. (a) 1000 J; (b) 20 m/sec; (c) 2.0 sec.

1-28. (a) 5.2×10^6 J; (b) 580 m.

1-29. 2.7×10^4 sec. or 7.5 hr.

1-30. 150 W.

Chapter Two
Simple Vibrating Systems

Questions

2-1. Give some examples of periodic motion.

2-2. A boy bounces a tennis ball on a racquet so that it moves vertically and goes to the same height each bounce. Is the motion of the ball simple harmonic? Does the period depend on the amplitude of the motion, i.e. the height to which the ball rises on each bounce?

2-3. Referring to Question 2, sketch a graph of the displacement of the tennis ball above the racquet as a function of time.

2-4. Again referring to Question 2, sketch a graph of the speed of the tennis ball as a function of time. Do the same for the acceleration.

2-5. A mass m hung on a spring of force constant k is moving vertically with simple harmonic motion. The amplitude of the motion is A. How could you calculate the velocity of the mass as it goes through the equilibrium position?

2-6. When the amplitude of the motion of Question 2-5 is reduced to half its initial value by frictional forces, what fraction of the mechanical energy of the system has disappeared? Where has it gone?

2-7. Find the broadcast frequencies in hertz of some local radio and television stations.

2-8. Give some musical examples of damped vibrations.

2-9. What will be the effect of a layer of tape wrapped around one prong of a tuning fork?

Problems

2-1. A student driving to school travels as follows: he travels 20 miles/hr for the first three minutes; he then speeds up to go 60 miles/hr for the next five miles; the next two miles require three minutes; then he gets caught in a traffic jam and goes nowhere for 1 minute; and the last two miles to school the best he can do is 15 miles/hr. (a) Make a table showing his distance from home at the end of each of these intervals and his speed during that interval. (b) Plot a graph of his distance from home as a function of the time in minutes since he left. (c) On the same graph plot his speed as a function of time in minutes. Assume that no time is required to change speed.

2-2. A stone is dropped from a tower. The distance D in meters it has fallen t seconds after being dropped is given by the formula

$$D = 4.9t^2$$

(a) Make a table showing the distance fallen at the end of each second up to 4 seconds. (b) Plot this as a graph of distance fallen vs. time.

2-3. If a ball is thrown vertically upward with a speed of 80 feet per second, its height h in feet above the ground t seconds after being thrown is given by the formula

$$h = 80t - 16t^2$$

(a) Plot a graph showing the height of the ball above the ground at the end of 0, 1, 2—etc. seconds after being thrown. (b) When does it reach its highest point? (c) How high does it go? (d) When does it hit the ground?

2-4. A certain spring requires a force of 5 newtons to stretch it 40 centimeters. (a) How much work in joules is required to stretch it this distance? (b) How much work will be required to stretch it 60 centimeters?

2-5. (a) If a mass of 0.5 kilogram is hung on the spring of Problem 2-4, what will be the frequency of oscillation? (b) What should the mass be to halve the frequency?

2-6. A certain spring requires 2 joules of work to stretch it 0.5 meter. (a) What force is required to stretch it this distance? (b) How much work will be required to stretch it one meter?

2-7. A mass hung on a particular spring stretches it 2.45 centimeters. What will be the oscillation frequency of this system?

2-8. The mass of 0.5 kilogram hung on the spring of Problem 2-4 is pulled 40 centimeters down from its equilibrium position and then released. What will be its speed when it passes through the equilibrium position?

2-9. Refer to Fig. 3, p. 28. The vibrating system has a certain amount of mechanical energy remaining at the beginning of a vibration cycle. Estimate from the figure the percentage of this energy that is lost during the subsequent cycle.

Answers to Problems

2-1. (a)	Time-min	3	8	11	12	20
	Distance-mi	1	6	8	8	10
	Speed-mi/hr	20	60	40	0	15
2-2. (a)	Time-sec	0	1	2	3	4
	Distance-m	0	4.9	19.6	44	78

2-3. (b) 2.5 sec; (c) 100 ft; (d) 5 sec.

2-4. (a) 1.0 J; (b) 2.25 J.

2-5. (a) 0.80 Hz; (b) 2.0 kg.

2-6. (a) 8N; (b) 8J.

2-7. 3.2 Hz.

2-8. 2 m/sec.

2-9. About 45%

Chapter Three
Waves and Wave Propagation

Questions

3-1. Chemists generally express the densities of solids in terms of grams per cubic centimeter. How can this be changed to kilograms per cubic meter?

3-2. To look ahead a bit, which musical instruments might you expect to use transverse waves to produce sound? Which ones would you expect to use longitudinal waves?

3-3. Is water a compressible medium? Is steel?

3-4. When a freight train starts moving, the locomotive starts pulling the first car with an audible "clank"; the first car starts pulling the second car with another "clank", and so on. This sound travels the length of the train in a very short time, even though by that time the train is barely moving. Explain how this can be. Is the "clank" a transverse or longitudinal impulse?

3-5. Waves in deep water have a speed that depends on the wavelength, being greater for longer waves. Does Eq. 2, p. 41, still hold for these waves? For these waves, would you expect the wavelength to be halved if the frequency is doubled?

3-6. A sound source is on one end of a railroad flatcar moving along the track. Will a listener on the other end of the car hear a frequency shift because of the Doppler effect?

3-7. Waves in water move more slowly in shallow water than in deep water. Why do ocean waves coming into a beach appear to have their crests generally parallel to the shoreline?

3-8. Ocean waves are not reflected from a sandy beach. Why?

3-9. What is the absorption coefficient of a rigid wall? Of an open window?

Problems

3-1. A wire has a linear density of 10 grams per meter length. How tightly must it be stretched to provide a wave speed of 150 meters per second?

3-2. A clothesline has a total mass of 5 kilograms and is 20 meters long. It is stretched between poles to a tension of 400 newtons. (a) What is the speed of a wave on the line? (b) How long will it take an impulse to go from one pole to the other?

3-3. What will be the speed of sound waves in air at 10°C: (a) in meters per second; (b) in feet per second?

3-4. What is the air temperature (°C and °F) if the speed of sound is 350 meters per second?

3-5. (a) What is the wavelength of a sound wave of frequency 200 hertz traveling in hydrogen gas at 0° centigrade? (b) What is the wavelength in air at 20° centigrade? (c) If the air temperature is lowered to 0° centigrade and the wavelength is kept the same, what will be the new frequency?

3-6. (a) If a sound wave in carbon dioxide gas at 0°C has a wavelength of 0.5 meters, what is its frequency? (b) If the wavelength is 0.5 meters in air at 0°C, what is the frequency? (c) If the temperature of the air is increased to 20°C, and the frequency is kept the same as in part (b) above, what will be the new wavelength?

3-7. From Eq. (3), p. 43, and the data given in the text, calculate the density of air at 0°C.

3-8. The speed of sound may be taken as 1100 feet per second for many applications. (a) To what temperature in degrees Fahrenheit does 1100 feet per second correspond to? (b) What temperature in degrees Fahrenheit would be required to give a sound speed of 1200 feet per second?

3-9. Refer to Fig. 6, p. 30. If the tuning fork vibrates at a frequency of 120 hertz and is moved in the direction shown in the figure at a speed of 36 centimeters per second, how far apart are the individual peaks inscribed on the plate?

3-10. Refer to Fig. 6, p. 30. If the tuning fork is moved across the plate with a speed of 24 centimeters per second, and inscribes peaks on the plate 2 millimeters apart, what is the frequency of the tuning fork?

3-11. Radio waves travel with the speed of light, 3.0×10^8 meters per second. (a) What is the wavelength of the signal broadcast by a radio station whose frequency is 150 megahertz? (b) What is the frequency of a signal whose wavelength is 60 centimeters?

3-12. (a) An "A" tuning fork (440 hertz) is sounded in air at 20°C. What is the wavelength of the sound waves produced; (1) in meters? (2) in feet? (b) The sound waves from the 440 cycle fork enter water at 15°C. What is their wavelength in the water, in meters and in feet?

3-13. (a) A man claps his hands and hears an echo 0.2 seconds later. How many meters distant is the reflecting surface? (Temperature is 20°C). (b) He claps his hands in front of another wall 200 meters distant. How many seconds later will he hear the echo?

3-14. A man claps his hands in front of a flight of steps, and hears a momentary musical sound of 275 hertz due to successive reflections from the steps. How wide are the steps?

3-15. If the steps of Problem 3-14 are 15 inches wide, what is the frequency of the reflected sound?

3-16. The man claps his hands while standing midway between two reflecting walls 20 feet apart. The sound impulse produced reflects back and forth between the walls, so that the man hears a sound consisting of a succession of impulses. What is the frequency of this sound?

3-17. A bell at a railroad crossing emits a sound of frequency 400 hertz. A passenger in a train approaching the crossing hears an apparent frequency of 420 hertz. (a) How fast is the train approaching the crossing, in feet per second? (b) What apparent frequency will the passenger hear after the train has passed the crossing? (Refer to Fig. 14(a), p. 45.)

3-18. A bell at a railroad crossing emits a sound of frequency 500 hertz. A train is approaching the crossing at 60 miles per hour. (a) What apparent frequency does a passenger in the train hear? (b) What will be the apparent frequency after the train passes the crossing?

3-19. A train moving 30 miles per hour is approaching a man standing on the track. The train blows its whistle, producing a sound of 240 hertz. What frequency does the man hear? (Refer to Fig. 14(b), p. 45.)

3-20. A clarinet player is sounding a sustained tone of 147 hertz. A second player sounds what he intends to be the same note, but hears 3 beats per second. What frequency is he playing?

3-21. A tuning fork produces a sound of 440 hertz. A second fork sounded with it produces 3 beats per second. Some tape is wrapped around one of the prongs of the second fork, and it is observed to still produce 3 beats per second when sounded with the first fork. What is the original frequency of the second fork, without tape.

3-22. A plane sound wave is reflected back and forth between parallel walls. After how many reflections will the wave be reduced in intensity to 35% of its original value: (a) If the absorption coefficient of the material of the walls is 0.41, (b) if it is 0.10?

3-23. A clarinet is producing the sound power output given in Table II, p. 52. (a) If its efficiency is one percent, what power is the clarinet player expending? (b) Find the sound intensity produced by the clarinet at a distance of 4 meters, assuming that the instrument is in a region where there are no reflecting surfaces and that it radiates equally in all directions. (c) Find the sound intensity produced at 8 meters.

3-24. How many tubas, each blasting out the maximum sound power given in Table II, p. 52, would be required to give a sound intensity of 8×10^{-4} watts per square meter at a distance of 30 meters? Assume that the instruments radiate uniformly in all directions and that there are no reflections.

3-25. If a tuba player must expend 25 watts to produce the sound power given in Table II, p. 52, what is the efficiency of the instrument?

Answers to Problems

3-1. 225 N.
3-2. (a) 40 m/sec; (b) 0.5 sec.
3-3. (a) 338 m/sec; (b) 1109 ft/sec.
3-4. 30°C or 86°F.
3-5. (a) 6.35 m; (b) 1.72 m; (c) 193 Hz.
3-6. (a) 516 Hz; (b) 663 Hz; (c) 0.52 m.
3-7. 1.29 kg/m^3.
3-8. (a) 44°F; (b) 135°F.
3-9. 0.30 cm.
3-10. 120 Hz.
3-11. (a) 2.0 m; (b) 5.0×10^8 Hz.
3-12. (a) 0.78 m, 2.56 ft; (b) 3.3 m, 10.7 ft.
3-13. (a) 34.4 m; (b) 1.16 sec.
3-14. 2 ft.
3-15. 440 Hz.
3-16. 55 Hz.
3-17. (a) 55 ft/sec; (b) 380 Hz.
3-18. (a) 540 Hz; (b) 460 Hz.
3-19. 250 Hz.
3-20. 144 or 150 Hz.
3-21. 443 Hz.
3-22. (a) 2 reflections; (b) 10 reflections.
3-23. (a) 5W; (b) 2.5×10^{-4} W/m^2; (c) 6.3×10^{-5} W/m^2.
3-24. 45.
3-25. 0.8%.

Chapter Four
Complex Vibrations and Resonance

Questions

4-1. In Fig. 1, p. 57, suppose that one of the traveling waves, say the one moving to the right, has a somewhat larger amplitude than the other. What would be the appearance of the resulting combination of the two waves?

4-2. The vibration frequency of a mass hung on a spring depends on the mass, while the vibration frequency of a pendulum formed by a mass hung on a string does not depend on the mass. Why?

4-3. A small mass (of negligible dimensions) is fastened to the center of a string stretched between supports. For example, suppose a small beetle to be clinging tenaciously to the center of a cello string. What effect will this mass have on the modes of vibration of the string?

4-4. A hole is drilled in the closed end of the closed tube of Fig. 9, p. 66. How will this affect the frequencies of the modes of vibration of the tube?

4-5. A small piece is cut off the tip of a cone and the cut end left open. How will the frequencies of the modes of vibration of the truncated cone compare with those of the original cone?

4-6. The tip of the cone is cut off as in Problem 4-5 and the cut end is closed. How will the frequencies of the modes of vibration compare with those of the original cone?

4-7. Can a square membrane vibrate with a nodal line along a diagonal of the square?

4-8. Referring to Fig. 22, p. 81, can you think of an expression which will give a measure of what might be called the "sharpness" of the resonance peaks?

4-9. Where is zero frequency on the scale of Fig. 25(b), p. 83?

Problems

4-1. A string is stretched between supports 3 meters apart, the tension in it being such that the velocity of a wave on it is 150 meters per second. Find the frequencies of the first four vibration modes.

4-2. A string of density 0.01 kilograms/meter is stretched between supports 2 meters apart, the tension in it being 400 newtons. Find the frequencies of the first four vibration modes.

4-3. (a) A spring 3 feet long is hung from a support with the bottom end free. If the longitudinal wave velocity is 18 feet per second, find the frequencies of the first four vibration modes. (b) The same spring has the bottom end fixed. Find the frequencies of the first four vibration modes.

4-4. A tube one meter long, closed at both ends, is filled with carbon dioxide gas at 0°C. Find the frequencies of the first four vibration modes.

4-5. A tube 2 meters long, open at both ends, is filled with air at 20°C. Find the frequencies of the first four vibration modes. (Neglect end effects.)

4-6. A tube 1.2 meters long, closed at one end and open at the other, is filled with hydrogen gas at 0°C. Find the frequencies of the first four vibration modes. (Neglect end effects.)

4-7. A steel bar 2.5 meters long is held at the center. Find the frequencies of the first four longitudinal vibration modes.

4-8. Find the lowest frequency for longitudinal vibrations of a steel bar four feet long when it is held one foot from one end.

4-9. If the tuning fork on the box shown in Fig. 18, p. 76, has a frequency of 256 hertz, how long should the box be to resonate with the fork? (Assume the box is a closed tube, and neglect end effects.)

4-10. In Fig. 19, p. 78, if the fork has a frequency of 320 hertz, what air column lengths will resonate with it? (Assume the glass tube to be one meter long.)

4-11. (a) Taking the speed of sound as 332 meters per second at 0° centigrade, find the first four vibration frequencies of a tube 100 centimeters long, closed at one end and open at the other, containing air at 0°C. (b) Find the fundamental frequency of the same tube at room temperature, 20° centigrade. (c) Find how much the tube must be lengthened to have the same fundamental frequency at 20°C as the original 100 centimeter tube had at 0°C.

4-12. A string of density of 0.01 kilograms per meter length is stretched between supports 0.667 meters apart: (a) If the tension in the string is 100 newtons, what will be its fundamental frequency? (b) What tension would be needed to give double the frequency in part (a)? (c) What density would be required to give double the frequency, if the tension is 100 newtons?

4-13. The string of Problem 4-12, part (a), is sounded with another string of the same density and length. What must be the tension in the second string to give three beats per second in the resulting sound?

4-14. How long must an open tube be if its fundamental is to have the same frequency as the second mode of a closed tube 120 centimeters long? (Neglect end effects.)

4-15. The two tubes of Problem 4-14 have inside diameters of 3 centimeters. Do Problem 4-14 taking end effects into account.

Answers to Problems

4-1. 25, 50, 75, 100 Hz.
4-2. 50, 100, 150, 200 Hz.
4-3. (a) 1.5, 4.5, 7.5, 10.5 Hz; (b) 3.0, 6.0, 9.0, 12.0 Hz.

4-4. 129, 258, 387, 516 Hz.
4-5. 86, 172, 258, 344 Hz.
4-6. 265, 795, 1325, 1855 Hz.
4-7. 1000, 3000, 5000, 7000 Hz.
4-8. 4100 Hz.
4-9. 0.34 m.
4-10. 27 cm, 81cm.
4-11. (a) 83, 249, 415, 581 Hz; (b) 86 Hz; (c) 3.6 cm.
4-12. (a) 75 Hz; (b) 400 N; (c) 0.0025 kg/m.
4-13. 92 or 108 N.
4-14. 80 cm.
4-15. 78.8 cm.

Chapter Five
The Ear: Intensity and Loudness Levels

Questions

5-1. In a lever system, a small force acting over a large distance produces a large force acting over a small distance, and conversely. Justify this statement from the standpoint of conservation of energy.

5-2. Why can we hear in the left ear sounds coming to us from the right?

5-3. If the intensity of a sound is increased by a factor of 1000, by how many decibels is the intensity level increased?

5-4. If the sound pressure of a sound is increased by a factor of 1000, by how many decibels is the sound pressure level increased?

5-5. Doubling the sound pressure of a sound will increase the sound pressure level by how many decibels?

5-6. How many violins would be required to sound four times as loud as one violin?

5-7. A tone of frequency 1200 hertz has a level of 80 decibels. What must be the level of a 1600 hertz tone in order to be barely audible in the presence of the other?

5-8. What must be the level of an 800 hertz tone in order to be heard in the presence of the 1200 hertz 80 decibel tone?

Problems

5-1. A speaking voice was measured as giving an output of 8.8×10^{-5} watts. Find the intensity level in decibels produced by such a voice output at 3 meters distance, assuming the voice is completely isolated so that there are no reflections.

5-2. A sound source gives an intensity level of 66 decibels at a distance of 12 meters in an anechoic room. What is the power output of the sound source?

5-3. What sound pressure level will be produced by the voice of Problem 1 at the same distance?

5-4. A trumpet player sounds a tone of intensity level 60 decibels at a certain distance. The player then increases the intensity level to 75 decibels. By what factor has he increased the sound power output of the trumpet?

5-5. (a) Find the rms sound pressure corresponding to a unidirectional sound wave of intensity level 120 decibels. (b) How does this pressure compare with atmospheric pressure?

5-6. If the rms pressure in a unidirectional sound wave is one-tenth the atmospheric pressure, what sound level is produced?

5-7. A sound source of frequency 70 hertz is producing a sound level of 60 decibels. By what percentage must the power output of the source be increased in order to just hear it as louder?

5-8. A violin playing at a certain distance is observed to produce an average intensity level of 64 decibels. Find the intensity level produced by (a) two similarly played violins together; (b) four violins; (c) 10 violins; (d) 40 violins.

5-9. How many similarly played violins must be added to the 40 violins of Problem 5-8 to produce a just noticeable increase in intensity level? Assume a playing frequency of 200 hertz.

5-10. Find the intensity level of a barely audible tone of (a) 1000 hertz, (b) 100 hertz, and (c) 50 hertz.

5-11. Three sounds of frequency 1000 hertz have intensities of 70, 73, and 77 decibels when measured separately. What will be the intensity level of the three sounded together?

5-12. A loudspeaker is producing a sound of loudness level 60 phons at 1000 hertz. (a) In order to produce the same loudness level at 100 hertz, find its output in decibels. (b) By what factor is its power output increased at the lower frequency?

5-13. Repeat Problem 5-12 for a frequency of 50 hertz.

5-14. A sound of loudness level 75 phons and frequency 100 hertz is added to one of 80 phons and the same frequency. Find (a) the intensity level of each sound, (b) the intensity level of the sum, and (c) the loudness level of the sum.

5-15. A sound of intensity 2×10^{-5} watts per square meter and another sound of intensity 4×10^{-5} watts per square meter are added together. (a) If the sounds have a frequency of 50 hertz, find the intensity level in decibels of each sound and the intensity level of the two added together. (b) Find the loudness level in phons of each sound and the loudness level of the two added together.

5-16. (a) Find the loudness in sones of two sounds whose loudness levels are 64 phons and 74 phons, respectively, of different frequencies. (b) Find the resulting loudness level if the two sounds are added together.

Answers to Problems

5-1. 59 dB.
5-2. 7.2×10^{-3} W.
5-3. 1.8×10^{-2} N/m^2.
5-4. 32 times.
5-5. (a) 20 N/m^2; (b) 2×10^{-4} of atmospheric pressure.
5-6. 174 dB.
5-7. 15%.
5-8. (a) 67 dB; (b) 70 dB; (c) 74 dB; (d) 80 dB.
5-9. 4 violins.
5-10. (a) 6 dB; (b) 25 dB; (c) 40 dB.
5-11. 79 dB.
5-12. (a) 68 dB; (b) 6.3 times.
5-13. (a) 78 dB; (b) 63 times.
5-14. (a) about 79 and 84 dB; (b) about 85 dB; (c) about 81 phons.
5-15. (a) 73 dB, 76 dB, and 78 dB; (b) about 53, 57, and 60 phons.
5-16. (a) 5 and 10 sones; (b) 80 phons.

Chapter Six
Tone Quality

Questions

6-1. A tone of frequency 100 hertz is given a vibrato such that the frequency ranges over 3 percent above and below the average frequency. Give the actual frequency range in hertz.

6-2. Repeat Question 6-1 for a tone of frequency 2000 hertz.

6-3. A spring is wound so that adjacent turns are normally touching. What will the graph of displacement verus force, Fig. 9(b), p. 123, look like?

6-4. A sinusoidal force is applied to the spring of Question 6-3. What will the resulting displacement, Fig. 9(c), p. 123, look like?

Problems

6-1. A tone is composed of partials of frequencies 240, 360, and 480 hertz. At what frequency does the wave pattern repeat?

6-2. A tone of 160 hertz is added to the combination of Problem 6-1. At what frequency does the wave pattern repeat?

6-3. Draw the spectrum for the wave of Fig. 3(c), p. 111.

6-4. The third harmonic (dotted curve in Fig. 3(a), p. 111) is shifted in phase by a half cycle. Draw the resulting waveform.

6-5. Sketch the result of adding one wave to another wave of 3 times the frequency and 1/9 the amplitude. The relative phase is such that the two waves are maximum at the same instant.

6-6. A hypothetical instrument has a format region extending from 350 hertz to 550 hertz. In this region partials pass through undiminished in amplitude; outside it, amplitudes of the partials are reduced to 20 percent of their origianl values. A sawtooth wave, Fig. 6(a), p. 115 of frequency 100 hertz, is impressed on the instrument. Draw the spectrum of the output.

6-7. Repeat Problem 6-6 for a square wave of 100 hertz.

6-8. Two clarinets are sounding tones of 165 hertz and 167 hertz respectively. How many beats will there be between the third harmonics?

6-9. Two tones of frequencies 200 hertz and 350 hertz are sounded together. Write down the frequencies of some combination tones below 500 hertz.

6-10. Repeat Problem 6-9 for two tones of 200 hertz and 500 hertz.

Answers to Problems

6-1. 120 Hz.
6-2. 40 Hz.
6-8. 6.
6-9. 50, 100, 150, 300 Hz.
6-10. 100, 200, 300, 400 Hz.

Chapter Seven
Frequency and Pitch

Questions

7-1. How many cycles of a tone of frequency 100 hertz are required to give a sensation of pitch?

7-2. How many cycles of a tone of frequency 1000 hertz are required to give a sensation of pitch?

Problems

7-1. (a) By what percentage must a 250 hertz tone be increased in frequency in order to sound just noticeably sharper? (b) By how many cycles per second must a 2000 hertz tone be increased in order to sound just noticeably sharper?

7-2. What is the frequency of the periodicity of a tone having partials of 180, 270, and 360 hertz?

7-3. What is the frequency of the periodicity of a tone having partials of 180, 240, and 360 hertz?

Answers to Problems

7-1. (a) 1.2%; (b) 10 Hz.
7-2. 90 Hz.
7-3. 60 Hz.

Chapter Eight
Intervals, Scales, Tuning, and Temperament

Questions

8-1. Given a tone of frequency 240 hertz, find the frequency of a tone (a) a fourth higher, (b) a fifth higher, and (c) an octave higher.

8-2. Given the tone of 240 hertz, find the frequency of a tone (a) a fourth lower, (b) a fifth lower, and (c) an octave lower.

8-3. In the Pythagorean scale, what note makes an interval of ratio 9/4 with C?

8-4. Given a tone of frequency 240 hertz, find the frequency of a tone (a) a just minor third higher, and (b) a just major third higher.

8-5. Given a tone of frequency 240 hertz, find the frequency of a tone (a) a just minor third lower, and (b) a just major third lower.

8-6. What triad is represented by the proportion 1/6 :1/5 :1/4?

Problems

8-1. Find the frequencies of the notes of a Pythagorean diatonic scale starting on a C of frequency 256 hertz.

8-2. Calculate the frequency of F# in the scale of Problem 1.
8-3. Calculate the frequency of G# in the scale of Problem 1.
8-4. Given a C of frequency 256 hertz, find the number of beats per second that would occur between the note a just major third higher and the note a Pythagorean major third higher.
8-5. Find the frequency ratio of the one-quarter syntonic comma.
8-6. Starting with a C of 256 hertz, find the frequencies of the notes of a one-quarter comma meantone diatonic scale.
8-7. Build a just diatonic scale starting with a frequency of 240 hertz.
8-8. Designating the frequency of 240 hertz in Problem 8-7 as C_4, find two chords corresponding to each of the following vibration proportions: (a) 2:3:4; (b) 3:4:5; (c) 4:5:8; (d) 5:6:8; (e) 10:12:15. The lowest note of a chord is to be in the octave starting with C_4, and the scale may be extended upward as far as necessary. (There are no sharps or flats.)
8-9. A string 120 centimeters long gives the pitch C_3 when bowed near one end. At what distances from the bowed end of the string should frets be placed so as to allow the just diatonic scale to be played?
8-10. Given an organ tuned to the tempered scale with C_4 = 261.63 hertz, find the number of beats per second between the following:

(a) 3rd harmonic of C_4 and 2nd harmonic of G_4
(b) 3rd harmonic of F_4 and 2nd harmonic of C_5
(c) 5th harmonic of C_4 and 4th harmonic of E_4

(Use the scale frequencies given on p. 153; five significant figures are necessary.)
8-11. Calculate the number of cents in the interval of the major sixth (C-A) in (a) the Pythagorean scale; and (b) the just scale.
8-12. The seventh harmonic of the note C_2 is flat as compared with the B♭ in the tempered scale starting with C_4. Find the difference in cents.
8-13. Comparing the present standard of pitch with Handel's standard, what is the difference in cents?

Answers to Problems 8-14 and 8-15 are to be expressed in the subscript notation for musical pitch. Actual frequencies are not necessary.

8-14. (a) Find the pitches of the first six partial tones of a pipe open at both ends and sounding C_3 as its fundamental. (b) Find the pitches of the first six partial tones of a pipe open at both ends and sounding C_3 as its third harmonic. (c) A pipe closed at one end and open at the other sounds B_5 as its fifth harmonic. Find the pitches of the lower harmonics.
8-15. (a) A string is plucked at the center and sounds C_4 as its third harmonic. What pitches below the seventh harmonic will be present? (Assume that harmonics having a node at the point where the string is plucked will not sound.) (b) A string 250 centimeters long is plucked at a point 100 centimeters from one end and sounds G_3 as its second harmonic. What pitches below the seventh harmonic will be present?

Answers to Problems

8-1. 256, 288, 324, 341.3, 384, 432, 486, 512 Hz.
8-2. 364.5 Hz. 8-3. 410.1 Hz.
8-4. 4 beats/second. 8-5. 1.00311.
8-6. 256, 286.2, 320, 342.4, 382.8, 428.0, 478.5, 512 Hz.
8-7. 240, 270, 300, 320, 360, 400, 450, 480 Hz.

8-8. (a) C_4 G_4 C_5, F_4 C_5 F_5, A_4 E_5 A_5, E_4 B_4 E_5, G_4 D_5 G_5;
(b) G_4 C_5 E_5, D_4 G_4 B_4, C_4 F_4 A_4;
(c) C_4 E_4 C_5, F_4 A_4 F_5, G_4 B_4 G_5;
(d) A_4 C_5 F_5, E_4 G_4 C_5, B_4 D_5 G_5;
(e) A_4 C_5 E_5, E_4 G_4 B_4, *not* D_4 F_4 A_4.
8-9. D_3, 106.7 cm; E_3, 96.0 cm; F_3, 90.0 cm; G_3, 80.0 cm; A_3, 72.0 cm; B_3, 64.0 cm; C_4, 60.0 cm.
8-10. (a) 0.84 beats/sec; (b) 1.19 beats/sec; (c) 10.37 beats/sec.
8-11. (a) 906 cents; (b) 884 cents.
8-12. 31 cents.
8-13. 70 cents.
8-14. (a) C_3, C_4, G_4, C_5, E_5, G_5; (b) F_1, F_2, C_3, F_3, A_3, C_4; (c) G_3, D_5, B_5.
8-15. (a) F_2, C_4, A_4; (b) G_2, G_3, D_4, G_4, D_5.

Chapter Nine
Auditorium and Room Acoustics

Questions

9-1. In a room with a reverberation time T seconds, how long will it take the reverberant sound (from an impulse sound source) to fall to 10^{-3} of its original intensity?
9-2. We have available material of absorption coefficient 0.50, and another material of absorption coefficient 0.33. How much of each will be needed to get 100 absorption units?
9-3. An auditorium has a volume of 200,000 cubic feet. Find the optimum reverberation time for various kinds of music. What average value would you use?
9-4. What is the approximate absorption coefficient of an individual in an audience?

Problems

9-1. Check the statement on p. 163 that doubling the distance from a sound source in the open will reduce the intensity level by 6 decibels.
9-2. A certain hall has a length of 250 feet as measured from the front of the stage to the back wall. For a listener sitting halfway between the stage and the back wall, what is the time interval between the direct sound and the first reflection? (Assume the first reflection to come from the back wall.) Temperature is 68°F.
9-3. Calculate the reverberation time of the room discussed in the example on p. 170.
9-4. A certain auditorium is approximately 70 feet long, 50 feet wide, 40 feet high, and has 450 upholstered seats. The side walls and back are covered with a cellulose tile, the back of the stage and the ceiling and plaster, and the floor is cork tile. Assume the cellulose tile to have an absorption coefficient of 0.7, and the plaster and cork tile to have a coefficient of 0.06. Calculate the reverberation time at 500 hertz for this hall (a) with all the seats empty, and (b) with the seats all occupied. (c) What would be the optimum reverberation time for this hall for chamber music? (d) What would be the optimum reverberation time at 100 hertz?

9-5. A trumpet is sounded in the empty auditorium of Prob. 9-4 and produces a continuous sound power output as given in Table II, p. 52. What will be the intensity level of the reverberant sound in the auditorium?

9-6. A certain rehearsal hall is 50 feet long, 40 feet wide and 20 feet high. The floor is hardwood with an absorption coefficient of 0.04, the ceiling is plaster with an absorption coefficient of 0.10, and side walls and end walls are brick with an absorption coefficient of 0.20, all measured at 500 hertz. (a) Find the optimum reverberation time for this room for chamber music. (b) Calculate the actual reverberation time for this room. (c) Find how large an audience in this room (seated in upholstered seats) will bring its reverberation time down to the optimum value found above. (d) Find how many square feet of material of absorption coefficient 0.60 must be put on the side walls to give the optimum reverberation time, without an audience.

9-7. Given the room of Prob. 9-6 with the absorption necessary to get the optimum reverberation time, what power output of a sound source will be required to give a reverberant sound level of 76 decibels?

Answers to Problems

9-2. 0.22 sec. 9-3. 0.54 sec.
9-4. (a) 0.89 sec; (b) 0.80 sec; (c) 1.3 sec; (d) 1.8 sec.
9-5. 86 dB.
9-6. (a) 1.1 sec; (b) 2.0 sec; (c) 130; (d) 2000 ft^2.
9-7. 6.7×10^{-3} W.

Chapter Ten
The String Instruments

Questions

10-1. Sketch a graph of the lateral force of the bowed violin string on the bridge during a vibration cycle.

10-2. On the same time axis, sketch a graph of the force of the bowed violin string on the nut during a vibration cycle.

10-3. From Fig. 4, p. 194, sketch a graph of the force of the bowed string on the bow during a vibration cycle.

10-4. How many resonances below 1000 hertz are there in the response curve shown in Fig. 9, p. 205?

Problems

10-1. A violin string is bowed to sound G_3. It is bowed 1/5 the way along the string from the bridge to the nut. What is the "flyback" time, i.e. the time required for the string to move from configuration (a) to configuration (c)?

10-2. If the amplitude A_B of the string motion under the bow in Fig.4, p. 194, is one millimeter, what is the speed of the bow?

10-3. Verify that the lowest plate resonances given in Fig. 6, p. 199, are 1.5 semitones apart.

10-4. If a double bass is designed to have its main wood resonance at D_2, How many times larger than the violin must it be according to the linear enlargement principle?

10-5. How many times larger than the violin would the double bass be according to the scaling curve of Fig. 11, p. 211?

10-6. A guitar string has a length of 63 centimeters from bridge to nut. At what distances in centimeters from the nut must frets be placed to play a tempered chromatic scale up to and including the octave?

Answers to Problems

10-1. 1.0 millisec. 10-2. 2.5 cm/sec.
10-4. 6 times. 10-5. 3.5 times.
10-6. 3.54, 6.87, 10.02, 13.00, 15.80, 18.45, 20.95, 23.31, 25.54, 27.64, 29.63, 31.50 cm.

Chapter Eleven
The Woodwind Instruments, and Others

Questions

11-1. Make a sketch of the pressure amplitudes of the first two vibration modes in the air column of a clarinet showing where the vent-hole should be theoretically located for best favoring of the second mode.

11-2. Check the result of Question 11-1 against the clarinet dimensions given in Ch. 11. How well do they check?

11-3. Repeat Question 11-1 for the conical air column of an oboe.

11-4. Why must the vent-hole in the bassoon move up along the instrument as the scale is ascended?

Problems

11-1. Verify the statement on p. 224 that the length of the vibrating air column in the flute corresponds to a vibration frequency closer to $C\#_4$ than to C_4.

11-2. What should be the theoretical length (from the fipple hole to the far end) of the alto recorder?

11-3. The actual length of the alto recorder from the fipple hole to the far end is about 42 centimeters. Explain the discrepancy between this length and the theoretical length calculated in Problem 11-2.

11-4. Check the statement on p. 237 that an air column of length about 60 centimeters will give a resonance frequency corresponding to the lowest note on a clarinet.

11-5. Find the lowest frequency corresponding to the length (254 centimeters) of the bassoon air column. Compare with the actual frequency of the lowest note on the bassoon.

Answers to Problems

11-2. 49.3 cm.
11-3. The fipple hole has an acoustical mass equivalent to 7 centimeters length of the recorder bore.
11-5. 67.7 Hz; B_1 = 58.3 Hz, 260 cents lower.

Chapter Twelve
The Brass Instruments

Questions

12–1. What do the French horn and the bass trombone have in common?

12–2. A large perforated rubber stopper (e.g. one of about a 6 centimeter diameter with a 2 centimeter diameter hole) is pushed into the bell of a trumpet. How will this affect the modes of the trumpet?

Problems

12–1. Calculate the length of an open tube that will give the same frequency ($B\flat_2$) as the trombone with the slide in.

12–2. Using the result of Problem 12–1, calculate the lengths of tubing added by pulling the slide out to positions 2, 3, and 4.

12–3. The valve slides for the first two valves on a trumpet are adjusted so that the trumpet is in tune with the tempered scale when the valves are used singly. What will be the discrepancy in cents when the two valves are used together?

Answers to Problems

12–1. 295 cm.

12–2. 17.6 cm, 36.2 cm, 55.9 cm.

12–3. 11 cents sharp.

Chapter Thirteen
The Piano, and Others

Questions

13–1. Can the tone of a note played on a harpsichord be affected by the manner of striking the key?

Problems

13–1. The C_4 strings on a particular piano have a length of 0.64 meters and a mass of 3.8×10^{-3} kilograms. To what tension must they be stretched, in newtons? In pounds?

13–2. Check the statement on p. 290 that a difference of two cents between two strings for C_4 will give about one beat in three seconds.

Answers to Problems

13–1. 666 N or 150 lb.

Chapter Fourteen
The Percussion Instruments

Problems

14–1. If a kettledrum can cover the range F_2 to B_2, by what factor does the tension in the head increase in going from the lowest note to the highest?

14–2. A 28-inch kettledrum has a head whose density is 0.03 grams per square centimeter. What must be the tension in the head (newtons per meter) if it is to sound F_2?

Answers to Problems

14–1. 2 times.

14–2. 777 N/m.

Chapter Fifteen
The Electronic Production of Sound

Problems

15–1. A pure tone of 10 kilohertz is recorded on a disc record at the standard speed of 33-1/3 revolutions per minute, being recorded as a wavy groove. If the groove is toward the center of the record and has a diameter of 4 inches, what is the wavelength of the groove, in inches?

Answers to Problems

15–1. 7×10^{-4} in.