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.

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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: kilometer, megameter, millimeter, millimeter.
Questions and Problems

A car is going around a circular curve at a constant speed. What is the acceleration? (a) A car is moving along a straight road at a constant speed. Does the astronaut have to worry about such mundane things as his head on a door frame? Express Eq. (4), p. 14, in English units, using the pound as the unit of force and mass.

In Fig. 7, p. 18, what is the resultant of all the forces on the object due to the pressure of the fluid? Is physical work done by a person (a) in raising a bucket of water, (b) carrying it across the yard, and (c) pouring it into a tub?

The kinetic energy $W$ in joules possessed by a mass of $m$ kilograms with a velocity of $v$ meters per second is given by

$$W = \frac{1}{2}mv^2.$$

Give a reason (guided by intuition) why the velocity must be squared? Find the wattage ratings of some home appliances.

Using the relation 1 foot = 0.3048 meters, work out the following to 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) $0.00000005 \times 2,500,000,000 \times 100,000,000,000$
(b) $2,500,000 \times 3,000,000$
(c) $0.000005 \times 400 \times 0.000060$
(d) $30,000 \times 0.000020 \times 0.0000020 $
(e) $0.000050 \times 200 \times 0.0000030$

1-4. Given the radius of the earth at $4.0 \times 10^3$ 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:

$1 \text{ km/hr} = \text{___________ ft/sec.}$
$1 \text{ cm/sec} = \text{___________ ft/min.}$
$1 \text{ knot} = \text{___________ cm/sec.}$
$60 \text{ mi/hr} = \text{___________ ft/sec.}$

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 ($93 \times 10^6$ 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.)
Questions and Problems

1. The distance from the earth to the moon, in round numbers, is 200 miles. How long will it take a flash of light to leave the earth, reflect the moon, and return to the earth, if light travels at a speed of 93,500 miles per second? (Use scientific notation and the proper significant figures.)

10. One newton equals how many pounds force?

11. The formula \( D = 8 \times t \) is valid for consistent units of distance, and time. Find a formula which will give the distance \( D \) in feet in \( t \) minutes by a car going \( S \) miles/hr.

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

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

14. A force of 10 newtons is exerted on a 20 kilogram mass initially at rest. How fast will the mass then be moving?

15. A force of 10 newtons acts on a 5 kilogram mass originally at rest. How fast will it go while stopping?

16. A ball of mass 0.10 kilograms is struck by a club and given a velocity 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.

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

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

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

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

21. A cylindrical can contains 10 kilograms of water. If the bottom is 12 inches in diameter, what is the pressure on it in newtons per square meter?

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

23. A force of 10 newtons is exerted on a 20 kilogram mass initially at rest. Find the acceleration of the ball, and (b) the force exerted on it.

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

(See Question 1-16.) In Problem 1-23, (a) find the speed of the 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 cm²; 16.4 cm³; 2.59 x 10⁶ m².

1-3. (a) 1.25 x 10⁻¹⁴; (b) 5 x 10⁻¹⁵; (c) 1; (d) 4 x 10⁻¹⁵; (e) 3.3 x 10⁻⁶.

1-4. (a) 2.1 x 10⁷ ft; (b) 6.4 x 10⁸ cm; (c) 2.0 x 10⁶ mi²; (d) 5.6 x 10¹⁵ ft²;

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

1-6. 1.9 x 10⁷ 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 = 8 S m/hr X t min.

1-12. (a) 7.5 mi/hr sec; (b) 11 ft/sec²; (c) 4.0 x 10⁴ ft/ft/hr/see; (d) 4.0 x 10⁴ ft/sec hr (e) 90 mi/hr or 192 ft/sec.

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

1-14. 6 m/sec.

1-15. 10 sec.

1-16. (a) 1.6 x 10⁴ m/sec²; (b) 1.6 x 10³ N.

1-17. (a) 2 x 10⁵ m/sec²; (b) 4 x 10³ N.

1-18. 706 N; 118 N.

1-19. 1.0 x 10⁶ kg.

1-20. (a) 10 m; (b) 2.0 x 10⁵ N/m².

1-21. 1.1 x 10⁵ N/m².

1-22. 7.4 x 10⁵ N.

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

1-24. (a) 50 m/sec²; (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 x 10⁶ J; (b) 580 m.

1-29. 2.7 x 10⁸ sec or 7.5 hr.

1-30. 150 W.
Chapter Two
Simple Vibrating Systems

Give some examples of periodic motion.
A boy bounces a tennis ball on a racquet so that it moves vertically to the same height each bounce. Is the motion of the ball simple? Does the period depend on the amplitude of the motion, i.e. the to which the ball rises on each bounce?
Referring to Question 2, sketch a graph of the displacement of the ball above the racquet as a function of time.
Again referring to Question 2, sketch a graph of the speed of the ball as a function of time. Do the same for the acceleration.
A mass $m$ hung on a spring of force constant $k$ is moving vertically simple harmonic motion. The amplitude of the motion is $A$. How could Iculate the velocity of the mass as it goes through the equilibrium $n$?
When the amplitude of the motion of Question 2-5 is reduced to half its value by frictional forces, what fraction of the mechanical energy of the system has disappeared? Where has it gone?
Find the broadcast frequencies in hertz of some local radio and television stations.
Give some musical examples of damped vibrations.
What will be the effect of a layer of tape wrapped around one prong of a fork?

A student driving to school travels as follows: he travels 20 miles/hr first three minutes; he then speeds up to go 60 miles/hr for the next two miles require three minutes; then he gets caught in a jam and goes nowhere for 1 minute; and the last two miles to school he can do is 15 miles/hr. (a) Make a table showing his distance from his home at the end of each of these intervals and his speed during that interval. (b) Graph his speed as a function of time. Assume that no time is required to change speed.
A stone is dropped from a tower. The distance $D$ in meters it has seconds after being dropped is given by the formula

$$D = \frac{9}{2}t^2$$

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 graph showing the height of the ball above the ground at the end of $\text{etc.}$ 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?

Questions and Problems

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.
2-5. (a) 0.80 Hz; (b) 2.0 kg.
2-7. 3.2 Hz.
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?
Questions and Problems

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?
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 parallel to the shoreline?
5. Ocean waves are not reflected from a sandy beach. Why?
3. What is the absorption coefficient of a rigid wall? Of an open window?

ems
1. A wire has a linear density of 10 grams per meter length. How many meters must it be stretched to provide a wave speed of 150 meters per second?
2. A clothesline has a total mass of 5 kilograms and is 20 meters long, stretched between poles to a tension of 400 newtons. (a) What is the tension on the line? (b) How long will it take an impulse to go from one pole to the other?
3. What will be the speed of sound waves in air at 10°C: (a) in meters per second; (b) in feet per second?
4. What is the air temperature (°C and °F) if the speed of sound is 350 s per second?
5. (a) What is the wavelength of a sound wave of frequency 200 hertz in hydrogen gas at 0° centigrade? (b) What is the wavelength in air at 10° centigrade? (c) If the air temperature is lowered to 0° centigrade and the length is kept the same, what will be the new frequency?
6. (a) What is the wavelength of sound waves in carbon dioxide gas at 0°C has a wavelength of 1 meter, what is its frequency? (b) If the wavelength is 0.5 meters in air at what is the frequency? (c) If the temperature of the air is increased to and the frequency is kept the same as in part (b) above, what will be the wavelength?
7. From Eq. (3), p. 43, and the data given in the text, calculate the speed of air at 0°C.
8. The speed of sound may be taken as 1100 feet per second for many stations. (a) To what temperature in degrees Fahrenheit does 1100 feet per second correspond to? (b) What temperature in degree Fahrenheit would occur to give a sound speed of 1200 feet per second?
9. Refer to Fig. 6, p. 30. If the tuning fork vibrates at a frequency of 440 hertz and is moved in the direction shown in the figure at a speed of 36 meters per second, how far apart are the individual peaks inscribed on the scale?
10. Refer to Fig. 6, p. 30. If the tuning fork is moved across the plate a speed of 24 centimeters per second, and inscribes peaks on the plate 2 centimeters apart, what is the frequency of the tuning fork?
11. Radio waves travel with the speed of light, 3.0 x 10^8 meters per second. (a) What is the wavelength of the signal broadcast by a radio station if the frequency is 150 megahertz? (b) What is the frequency of a signal with wavelength 60 centimeters?
12. (a) An "A" tuning fork (440 hertz) is sounded in air at 20°C. What wavelength of the sound waves produced? (1) in meters? (2) in feet? (b) Sound waves from the 440 cycle fork enter water at 15°C. What is their length in the water, in meters and in feet?

Questions and Problems

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 0.1, (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 x 10^-4 watt 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?
Chapter Four
Complex Vibrations and Resonance

Questions and Problems

1. 225 N.

3. 2. (a) 40 m/sec; (b) 0.5 sec.

5. (a) 339 m/sec; (b) 1109 ft/sec.

7. 3. (a) 3.2 kg/m³; (b) 135°F.

9. 0.30 cm.

1. (a) 2.0 m; (b) 6.0x10⁸ Hz.

2. (a) 0.78 m, 2.56 ft.; (b) 3.3 m, 10.7 ft.

4. (a) 34.4 m; (b) 1.16 sec.

6. (a) 96 Hz; (b) 380 Hz.

8. 2 reflections; (b) 10 reflections.

10. 2 reflections.

12. 5 W; (b) 2.5x10⁻⁴ W/m²; (c) 6.3x10⁻⁸ W/m².

14. 0.8%.

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 3 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°C 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°C 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.
Questions and Problems

1. 129, 258, 387, 516 Hz.
2. 265, 795, 1325, 1855 Hz.
3. 4100 Hz.
4. 4.41 cm.
5. 27 cm, 81 cm.
6. (a) 83, 249, 415, 581 Hz; (b) 62 Hz; (c) 3.6 cm.
7. (a) 75 Hz; (b) 400 N; (c) 0.0025 kg/m.
8. 92 or 108 N.
9. 78.8 cm.

Chapter Five
The Ear: Intensity and Loudness Levels

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

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

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

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

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

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

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

Questions and Problems

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 sounds 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 $2 \times 10^{-5}$ watts per square meter and another sound of intensity $4 \times 10^{-6}$ 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 phons of 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 x 10^{-3} W.
5-3. 1.8 x 10^{-2} N/m^2. 5-4. 32 times.
5-5. (a) 20 N/m^2; (b) 2 x 10^{-6} 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) 63 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; (b) 40 dB. 5-16. (a) 5 and 10 sones; (b) 80 phons.
Chapter Six
Tone Quality

Sections

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 versus force, Fig. 9(b), p. 123, look like?
6-4. A sinusoidal force is applied to the spring of Question 6-3. What will be 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 use 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 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 original 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 400 hertz.

Answers to Problems

1. 120 Hz.
2. 40 Hz.
3. 6.
4. 50, 100, 150, 300 Hz.
5. 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.
Questions and Problems

- 2. Calculate the frequency of F# in the scale of Problem 1.
- 3. Calculate the frequency of G# in the scale of Problem 1.
- 4. Given a C of frequency 256 hertz, find the number of beats per second that would occur between the note a major third higher and the note a Pythagorean major third higher.
- 5. Find the frequency ratio of the one-quarter syntonic comma.
- 6. Starting with a C of 256 hertz, find the frequencies of the notes of a quarter comma meantone diatonic scale.
- 7. Build a just diatonic scale starting with a frequency of 240 hertz.
- 8. Designating the frequency of 240 hertz in Problem 8-7 as C4, find chords corresponding to each of the following vibration proportions: (a) 3:4:5; (b) 4:5:8; (c) 5:6:8; (d) 10:12:15. The lowest note of a chord is to be in the octave starting with C4, and the scale may be extended as far as necessary. (There are no sharps or flats.)
- 9. A string 120 centimeters long gives the pitch C3 when bowed near 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?
- 10. Given an organ tuned to the tempered scale with C4 = 261.63 hertz, the number of beats per second between the following:

(a) 3rd harmonic of C4 and 2nd harmonic of C4
(b) 3rd harmonic of F4 and 2nd harmonic of C4
(c) 5th harmonic of C4 and 4th harmonic of E4

the scale frequencies given on p. 153; five significant figures are necessary.
- 11. Calculate the number of cents in the interval of the major sixth in (a) the Pythagorean scale; and (b) the just scale.
- 12. The seventh harmonic of the note C4 is flat as compared with the tempered scale starting with C4. Find the difference in cents.
- 13. Comparing the present standard of pitch with Handel's standard, is the difference in cents?

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

14. (a) Find the pitches of the first six partial tones of a pipe open at one end and sounding C3 as its fundamental. (b) Find the pitches of the six partial tones of a pipe open at both ends and sounding C3 as its harmonic. (c) A pipe closed at one end and open at the other sounds B5 as its fifth harmonic. Find the pitches of the lower harmonics.
15. (a) A string is plucked at the center and sounds C2 as its third harmonic. What pitches below the seventh harmonic will be present? (Assume harmonics having a node at the point where the string is plucked will not have a node at the point where it is plucked.) (b) A string 100 centimeters long is plucked at a point 100 centimeters one end and sounds G3 as its second harmonic. What pitches below the first harmonic will be present?
Questions and Problems

1-5. A trumpet is sounded in the empty auditorium of Prob. 9-4 and duces a continuous sound power output as given in Table II, p. 52. What be the intensity level of the reverberant sound in the auditorium?

1-6. 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 tile with an absorption coefficient of 0.10, and side walls and end walls brick with an absorption coefficient of 0.20, all measured at 500 hertz. Find the optimum reverberation time for this room for chamber music. Calculate the actual reverberation time for this room. (c) Find how large audience in this room (seated in upholstered seats) will bring its reverberation time down to the optimum value found above. (d) Find how many are feet of material of absorption coefficient 0.50 must be put on the side is to give the optimum reverberation time, without an audience.

1-7. Given the room of Prob. 9-6 with the absorption necessary to get the ismum reverberation time, what power output of a sound source will be aired to give a reverberant sound level of 76 decibels?

Answers to Problems

9-3. 0.54 sec.
9-4. 1.3 sec.
9-5. 1.8 sec.
9-6. 2.0 sec.
9-7. 130 sec.
9-8. 2000 ft².
9-9. 6.7 x 10⁻³ W.

Chapter Ten
The String Instruments

Questions

0-1. Sketch a graph of the lateral force of the bowed violin string on the ge during a vibration cycle.

0-2. On the same time axis, sketch a graph of the force of the bowed astringent on the nut during a vibration cycle.

0-3. From Fig. 4, 4. p. 194, sketch a graph of the force of the bowed string he bow during a vibration cycle.

0-4. How many resonances below 1000 hertz are there in the response shown in Fig. 9, p. 205?

Problems

0-1. A violin string is bowed to sound G₂. It is bowed 1/5 the way along string from the bridge to the nut. What is the "flyback" time, i.e. the time it takes the bow to move from configuration (a) to configuration (c)?

0-2. If the amplitude A₂ of the string motion under the bow in Fig. 4, p. is one millimeter, what is the speed of the bow?

0-3. Verify that the lowest plate resonances given in Fig. 6, p. 199, are two octaves apart.

0-4. If a double bass is designed to have its main wood resonance at D₁, many times larger than the violin must it be according to the linear arrangement principle?

Answers to Problems

10-1. How many times larger than the violin would the double bass be according to the scaling curve of Fig. 11, p. 211?

10-2. What is the length of a guitar string that 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 millisecond. 10-2. 2.5 cm/sec. 10-3. 6 times. 10-4. 3.5 times. 10-5. 3.5 times. 10-6. 3.54, 6.87, 13.02, 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 positioned 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 C₄ than to C₅.

11-2. What is the theoretical length (from the flue hole to the far end) of the alt recorder?

11-3. The actual length of the alto recorder from the flue 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 flue hole has an acoustical mass equivalent to 7 centimeters length of the recorder bore.

11-5. 67.7 Hz; B₁ = 58.3 Hz, 260 cents lower.
Chapter Twelve
The Brass Instruments

Sessions
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
    impet. How will this affect the modes of the trumpet?

Problems
12-1. Calculate the length of an open tube that will give the same fre-
    quency (Bb4) as the trombone with the slide in.
12-2. Using the result of Problem 12-1, calculate the lengths of tubu-
    ded 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
    it the trumpet is in tune with the tempered scale when the valves are used
    glibly. What will be the discrepancy in cents when the two valves are used
    other?

Solutions to Problems
-1. 295 cm.
-3. 11 cents sharp.
12-2. 17.6 cm, 36.2 cm, 55.9 cm.

Chapter Thirteen
The Piano, and Others

Sessions
13-1. Can the tone of a note played on a harpsichord be affected by the
    inner of striking the key?

Problems
13-1. The C4 strings on a particular piano have a length of 0.64 meters and
    a mass of 3.8 x 10^-7 kilograms. To what tension must they be stretched, in
    tons? In pounds?
3-2. Check the statement on p. 290 that a difference of two cents be-
    en two strings for C4 will give about one beat in three seconds.

Solutions to Problems
3-1. 666 N or 150 lb.

Chapter Fourteen
The Percussion Instruments

Problems
14-1. If a kettle drum can cover the range F2 to B2, by what factor does
    the tension in the head increase in going from the lowest note to the highest?
14-2. A 28-inch kettle drum 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 F2?

Solutions 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?

Solutions to Problems
15-1. 7 x 10^-4 in.
Appendix
Powers of Ten and Simple Logarithms

Problems
-1. Express as powers of ten, as for example
   \[ 3.16 = 10 \times 3.16 = 10 \times 10^{0.5} = 10^{1.5} \]
   (a) 3160; 3.16 \times 10^6; 0.00316
   (b) 21.6; 683 (= 31.6 \times 21.6).
   (c) 1.46; 1460.
   (d) 12.6; 1.26 \times 10^{-4}.

-2. Find the logarithms of the following numbers:
   (a) 2; 4; 8; 10.
   (b) 15; 20; 25; 100.
   (c) 150; 400; 2000; 5 \times 10^5.
   (d) 0.2; 0.004; 10^{-4}; 5 \times 10^{-6}.

Answers to Problems
-1. (a) \[10^{3.5}; 10^{0.5}; 10^{-2.5}.\]
   (b) \[10^{3.3}; 10^{2.33}.\]
   (c) \[10^{0.17}; 10^{3.17}.\]
   (d) \[10^{1.10}; 10^{3.90}.\]

-2. (a) 0.301; 0.602; 0.903; 1.000.
   (b) 1.178; 1.301; 1.398; 2.000.
   (c) 2.176; 2.602; 3.301; 6.000.
   (d) -0.699; -2.398; -6.000; -5.301.