

EXAMPLES FOR PRACTICE.

1. (*See* § 594.) How long does it take a ray from the moon to reach the earth, the moon's distance being 240,000 miles?
2. The planet Jupiter is 496,000,000 miles from the sun. How long does it take a ray of light from the sun to reach the planet?
3. A ray of light from the sun is about 12,326 seconds longer in reaching the newly discovered planet Neptune than in reaching Jupiter. About how many miles farther from the sun is Neptune than Jupiter?
4. (*See* § 595.) A holds his book 1 foot, and B holds his 3 feet, from a certain candle. How much more light does A receive than B?
5. The planet Uranus is twice as far from the sun as the planet Saturn. How does the light received at Saturn compare in intensity with that received at Uranus?
6. (*See* § 650.) How many times is the ordinary heat of the sun increased by a burning glass with an area of 10 square inches, the focus of which has an area of $\frac{1}{10}$ of a square inch?
7. A convex lens has a focus $\frac{1}{5}$ of a square inch in area, and increases the heat of ordinary sun-light 200 times; what is the area of the lens?

CHAPTER XV.

ACOUSTICS.

716. ACOUSTICS is the science that treats of sound.

717. NATURE AND ORIGIN OF SOUND.—Sound is an impression made on the organs of hearing by the vibrations of elastic bodies, transmitted through the air or some other medium. These vibrations may be compared to the minute waves which ripple the surface of a pond when a stone is thrown in,—spreading out from a centre, but growing smaller and smaller as they recede, till finally they are no longer perceptible. They are produced by percussion, or any shock which gives an impulse to the particles of the sounding body. There is no sound that can not be traced to mechanical action.

718. Bodies whose vibrations produce clear and regular

sounds are called Sonorous. Bell-metal, glass, the head of a drum, are sonorous.

719. That sound is produced by vibrations is proved in various ways. A person standing near a piano-forte or an organ, when it is played, feels a tremulous motion in the floor of the apartment, as well as in the instrument itself if he touches it. We perceive the same tremor in a bell when in the act of being rung. In like manner, if we strike a tumbler so as to produce a sound, and then touch the top, we feel an internal agitation; and, when the vibrations are stopped, as they are by contact with the finger, the sound ceases with them. If we put water in a glass and produce a sound by rubbing the top with the finger, the liquid is agitated, and its motion continues until the sound dies away.—Place some fine sand on a square piece of glass, and, holding it firmly with a pair of pincers, draw a violin-bow along the edge. The sand is put in motion, and finally settles on those parts of the glass that have the least vibratory movement.—If a tuning-fork be struck and applied to the surface of mercury, minute undulations may be observed in the metal.

That these vibrations are communicated to the air and by it transmitted to the ear, also admits of easy proof. The rapid passage of a heavy cart or stage shakes the walls of a house. The discharge of artillery sometimes breaks windows. These effects are due to the vibrations suddenly produced in the air. If there is no air or other medium to transmit the vibrations to the ear, no sound is heard. We have already seen (§ 439) that a bell rung in an exhausted receiver can hardly be heard; if the air could be entirely removed, it would be wholly inaudible. Sound, therefore, does not leap from point to point, but is transmitted by vibrations communicated from one particle to another.

720. All sonorous bodies are elastic, but all elastic bodies are not sonorous.

Soft bodies are generally non-elastic, and consequently not sonorous. This is the case with cotton, for example, which yields little or no sound when struck by a hammer. It is on this account that music loses much of its effect in rooms with tapestried walls or curtained windows. Hence, also, a speaker finds it more difficult to make himself heard in a crowded room than in one that is empty.

721. TRANSMISSION OF SOUND.—All the sounds that or-

716. What is Acoustics? 717. What is Sound? How are sound-waves produced? To what is every sound traceable? 718. What bodies are called Sonorous? Give examples. 719. How is it proved by familiar experiments that sound is produced by vibrations? If a tuning-fork be struck and applied to the surface of mercury, what may be observed? How is it proved that these vibrations are communicated to the air and by it transmitted to the ear? 720. What property belongs to all sonorous bodies? What bodies are, for the most part, not sonorous? Give examples. What follows from the fact that soft bodies are not sonorous? 721. By what are the sounds

dinarily reach our ears are transmitted to them by the air. Any material substance, however, that connects our organs of hearing with a vibrating body, may transmit the vibrations in the same way. Thus, with our heads immersed in water, we can hear a sound produced under the surface at a considerable distance. Here water is the transmitting medium.

722. Liquids are better conductors of sound than æri-form bodies, and solids than liquids.

Persons in boats can converse with each other at a great distance, because water is a good conductor of sound. When the ear is applied to one end of a long stick of timber, the scratch of a pin at the other end can be distinctly heard, owing to the conducting power of the wood. An approaching locomotive can be heard at a great distance by placing one's ear on the rails. The American Indians knew by experience the facility with which solids transmit sounds, and were in the habit of applying their ears to the earth when they suspected the approach of an enemy, or wanted a more distinct impression of any sound that attracted their attention.

723. The denser air is, the more readily it transmits sounds. On the tops of high mountains, where, as we have already learned, the atmosphere is rare, the human voice can be heard only a few rods off, and the report of a musket sounds no louder than the snapping of a whip at the level of the sea. On the other hand, the air in a diving-bell let down to the bottom of the sea, which is condensed by the upward pressure of the water, transmits sound so freely that those who descend can hardly speak to each other above their breath; conversation in an ordinary tone would pain the ear.—Frosty air is a much better conductor of sound than warm air. In the polar regions, conversation has been carried on by two persons a mile apart.

Still air of uniform density transmits sounds more freely than air which is agitated by variable currents or contains strata of different density. This is one reason why sounds are more distinctly heard by night than by day. Falling rain or snow interferes with the vibrations, and tends to make sounds less distinct; so, likewise, do contrary winds.

724. If the air were perfectly still and of uniform density, sound transmitted through it *would decrease in loudness as the square of the distance from the vibrating body*

we ordinarily hear, transmitted? What else may transmit sound-waves in the same way? 722. How do solid, liquid, and æri-form bodies compare, as conductors of sound? Give a proof of the conducting power of water. State some facts illustrating the facility with which solids conduct sound. 723. How do rare and dense air compare, as conductors of sound? Give examples. How does cold air compare with warm in conducting power? Under what circumstances does air transmit sound most freely? What is the effect of falling rain or snow? 724. If the air were perfectly still

increased. The report of a cannon, for instance, would seem only one-fourth as loud at a distance of 200 feet as at a distance of 100 feet.

725. VELOCITY OF SOUND.—Under ordinary circumstances, *sound is transmitted through air with a velocity of 1,120 feet in a second*, which is at the rate of a mile in about $4\frac{3}{4}$ seconds.

All sounds, whether loud or faint, high or low, are transmitted by a given medium with equal rapidity. Were it not so, there would be no such thing as harmony in musical performances, for the notes of the different instruments would reach the ear at different intervals.

Sound, it will be observed, travels much more slowly than light. The latter moves 192,000 miles while the former is going only 1,120 feet. The difference in their velocities is perceptible even at short distances. If we look at a man splitting wood a few rods off, we see the axe descend on the log some time before we hear the noise of the blow. So, the report of a cannon is not heard till after the flash is seen,—the interval being long or short according to its distance.

726. When the sound is accompanied with a flash, knowing the relative velocity of sound and light, we can calculate very nearly the distance from which it comes. We have only to notice the number of seconds that elapse after the flash is seen before the sound is heard, and multiplying this by 1,120, we get the distance in feet. The time which it takes the light to traverse the given distance and reach the eye, is so small that it does not enter into the calculation. For example, if a clap of thunder is heard 3 seconds after the accompanying flash is seen, the cloud from which they proceed is 3 times 1,120 (or 3,360) feet distant. The sooner the report follows the flash, the nearer the cloud.

727. Water transmits sound $4\frac{1}{2}$ times as rapidly as air; iron, 10 times; and different kinds of wood, from 11 to 17 times.

Place the ear at one end of a very long stick of timber, and let some one strike the other end with a hammer. The wood conducts the sound to the ear so much more quickly than the air that the blow is heard twice. So,

and of uniform density, what would be the law for the loudness of a sound heard at different distances? Give an example. 725. What is the velocity of sound? How is the velocity of sound affected by its loudness and pitch? What proof have we of this? How does the velocity of sound compare with that of light? Give some familiar instances showing their difference of velocity. 726. When the sound is accompanied with a flash, how may we calculate the distance from which it comes? Give an example. 727. With what velocity does water transmit sound, as compared with

when a bell at the end of a long iron tube is struck, two sounds are heard at the opposite extremity,—the first conducted by the iron, the second by the air within it.

728. **DISTANCE TO WHICH SOUND IS TRANSMITTED.**—So many changes are constantly taking place in the atmosphere, in its temperature, moisture, density, and the velocity and direction of its currents, that no universal law can be laid down as to the distance at which sound is audible. The human voice, when raised to its highest pitch and loudest tones, may be heard at the distance of an eighth of a mile; the report of a musket, at 5 miles.

Through the water, or in the atmosphere directly over it, sounds are transmitted to a great distance. The ringing of a bell under water has been heard across the whole breadth of Lake Geneva, not less than nine miles. The "all's well" of the sentinel at Gibraltar has been distinguished twelve miles off, and naval engagements have been heard at a distance of 200 miles. An eruption of the volcano of St. Vincent has been heard at Demerara, 340 miles off,—the greatest distance on record to which sound has been transmitted by the atmosphere.

729. **ACOUSTIC TUBES.**—It is their dispersion in the surrounding air that makes sounds finally inaudible. Hence, when they are confined within tubes, they are carried to a much greater distance. The slightest whisper has been heard through an iron pipe 3,120 feet (more than half a mile) in length.

This fact has been turned to account in several ways. The voice is conveyed by speaking-tubes from one part of a building to another, frequently to a considerable distance and by a circuitous route. The Stethoscope, an instrument for examining the lungs and other internal organs, is an application of the same principle. It is a hollow cylinder of wood with a funnel-shaped extremity, which is placed on the organ to be examined while the ear is applied to the other end. The sounds produced by the vital action within are thus conveyed to the ear, and enable the experienced examiner to judge whether the organ is in a healthy state.

air? Iron? Wood? What experiments prove that solids conduct sound more rapidly than air? 728. What makes it impossible to lay down a universal law as to the distance at which sound is audible? How far may the human voice be heard? The report of a musket? What instances are mentioned showing the great distance to which sound is transmitted by water? What is the greatest distance on record to which sound has been transmitted by the atmosphere? 729. What makes sounds finally inaudible? How may this difficulty be in a measure removed? How far has a faint whisper been heard through a tube? How has this principle been turned to

730. *The Speaking-trumpet.*—Even if the tube is short, the more intense pulsation excited in a column of confined air makes a given sound audible at a much greater distance than if it is at once diffused in the atmosphere. This is proved by the Speaking-trumpet, an instrument used by seamen and others who wish to give additional power to their voices. The narrowness of the tube prevents the easy flow of the air which the voice sets in vibration. The organs of articulation, therefore, operate on it with concentrated force, as they do on condensed air; and, consequently, when the vibrations escape from the tube, they are propelled to a greater distance. A loud voice with a speaking-trumpet 20 feet long, can be heard at a distance of three miles. No one can use the speaking-trumpet long without being exhausted, which shows that an unusual effort has to be made with the voice.

731. **INTERFERENCE OF SOUND.**—Two sets of vibrations of equal intensity, meeting in such a way that the depressions of one correspond with the elevations of the other, *interfere*, or neutralize each other, and an interval of silence is the result.

Cause a tuning-fork to vibrate and hold it over a cylindrical glass vessel. Vibrations will soon be communicated to the glass, and a musical note will be heard. Place a similar glass vessel at right angles to the first and opposite the tuning-fork, and the note previously heard will cease. Withdraw it, and the note is again heard. The vibrations of the first vessel produce the sound, but are neutralized by those of the second.

732. **REFLECTION OF SOUND.**—Vibrations striking a plane surface are reflected from it (like light and heat) in such a way as to make *the angle of reflection equal to the angle of incidence*.

733. *Echoes.*—When a sound is heard a second time by reflection, after a certain interval, an Echo is said to be produced. A sound is sometimes repeated more than once,

account? What instrument is constructed on this principle? Describe the Stethoscope, and its operation. 730. By whom is the Speaking-trumpet used? Explain the principle on which it operates. How far has a loud voice been heard with a speaking-trumpet? 731. What is meant by the Interference of sound, and how is it caused? Give an example. 732. What is the law for the reflection of sound? 733. What is an

according to the number of reflecting surfaces on which it strikes. An echo near Milan repeats a single syllable thirty times.

To be distinctly heard, the echo must not reach the ear till one-ninth of a second after the original sound has ceased. Otherwise they will run together and form one continuous sound. Hence, the reflecting surface must be a certain distance from where the original sound is produced. The farther it is off, the longer the reflected sounds will be in reaching the observer's ear, and the more syllables will be repeated. At Woodstock, England, there is an echo which repeats from 17 to 20 syllables; in this case the reflecting surface is distant about 2,300 feet. In mountainous regions echoes are quite common. There are several remarkable ones among the Alps; and the mountaineers contrive to sing one of their national songs in such time that the echo forms an agreeable accompaniment.

In ordinary rooms no echo is perceived, because the distance of the walls is so small that the reflected sound is mingled with the original one; but in large halls, unless the principles of Acoustics are regarded, an unpleasant echo follows the speaker's words and makes them confused and indistinct.

734. *Ear-trumpets*.—Ear-trumpets, used by deaf persons, concentrate and reflect to the interior membrane of the ear, vibrations that strike it, and thus render audible sounds that could not otherwise be heard. The principle on which they operate will be understood from Fig. 263.



The sounds enter the large end, and are united by successive reflections at the small end, which is applied to the ear. The outer part of the ear is itself of such a shape as to collect the sound-waves that strike it and reflect them to the membrane within. To enable them to hear more distinctly, we often see people putting up their hands behind their ears, so as to form a concave reflecting surface; in which case, the hand acts somewhat on the principle of the ear-trumpet. Instinct teaches animals to prick up their ears when they want to catch a sound more clearly.

Shells of a certain shape reflect from their inner surface the vibrations that strike it from the external air, and hence the peculiar sound that is heard when they are applied to the ear.

Echo? In what case may a sound be repeated more than once? How often does an echo near Milan repeat a syllable? What is essential to the distinctness of an echo? On what does the number of syllables repeated depend? Give an account of the echo at Woodstock, England. Where are echoes quite common? What is said of those in the Alps? Why is there no echo in ordinary rooms? 734. How is it that Ear-trumpets render audible sounds that could not otherwise be heard? What is said of the outer part of the ear? How is the hand made to act on the principle of a speaking-trumpet? Why do animals prick up their ears? Explain the roaring of

735. *Whispering Galleries*.—Sound reflected from curved surfaces follows the same law as light and heat. Let two large concave brass mirrors be placed opposite to each other, as shown in Fig. 213; the ticking of a watch, or the faintest whisper in the focus of one, is distinctly heard, after two reflections, at the focus of the other, though inaudible at any other point. Two persons with their backs to each other can thus carry on a conversation, while those between them are not aware that anything is being said.

An apartment in which such a reflection is produced by the walls is called a Whispering Gallery. An oval form is the best for such a gallery, because there are two points within, to either of which all the vibrations produced at the other are reflected at the same instant from every point of the surrounding walls. The dome of St. Paul's Church, London, and that of the Capitol at Washington, are examples of fine whispering galleries.

One of the most remarkable structures of this kind in ancient times was "the ear of Dionysius", a dungeon so called from the tyrant of Syracuse, by whom it was constructed. The walls and roof were so arranged that every sound from within was reflected and conveyed to a neighboring apartment, where the tyrant could ensconce himself and hear even the whispers of his unsuspecting victims.

736. *MUSICAL SOUNDS*.—Musical Sounds are produced by regular vibrations, uniform in their duration and intensity.

737. *Loudness, Pitch, and Quality*.—In connection with musical sounds, three things must be considered; their Loudness, their Pitch, and their Quality.

The Loudness of a musical sound depends on the extent of the vibrations producing it. The greater the vibrations, the louder is the sound.

The Pitch of a musical sound depends on the rapidity

shells. 735. What law does sound reflected from curved surfaces follow? Illustrate this law in the case of sounds reflected from two concave mirrors. What is a Whispering Gallery? What is the best form for such a gallery, and why? What buildings contain whispering galleries? Give an account of "the ear of Dionysius". 736. How are Musical Sounds produced? 737. What three things must be considered in connection with musical sounds? On what does the Loudness of a musical sound