12. How low should the background noise level be in a concert hall?
13. What is meant by a "shoebox" design?
14. Give an example of a successful concert hall having a shoebox design.
15. What are three sources of noise in a typical classroom?
16. What is the maximum noise level that will allow speech intelligibility in a typical classroom?
17. What is a desirable reverberation time in a classroom?

QUESTIONS FOR THOUGHT AND DISCUSSION

1. Why does the use of cushioned seats help to make the reverberation time of an auditorium independent of audience size?
2. Which is easier to correct, a reverberation time that is too long or one that is too short?
3. What are desirable reverberation times for speech and for orchestral music in an auditorium with $V = 1000\ \text{m}^3$?
4. An auditorium is thought to have excessive reverberation, especially at low frequency. It is proposed that the ceiling be covered with acoustic tile to reduce this. What do you think of this solution? Is there a better one?

EXERCISES

1. Compare the absorption of 100 m^2 of plastered wall with that of 100 m^2 of carpeted floor at
   (a) 125 Hz;
   (b) 2000 Hz.
2. An auditorium has dimensions 40 m × 20 m and a ceiling height of 15 m. The front and back walls are covered with plywood paneling; the side walls and ceiling are plaster. The floor is wood. There are 1100 wooden seats. Estimate the reverberation time (500 Hz) when
   (a) The hall is empty;
   (b) Half the seats are filled;
   (c) All the seats are occupied.
3. Estimate the time delay t_1 of the first reflected sound for a person seated near the center of the auditorium described in Exercise 2. Does the first reflection arrive from the side or from overhead?
4. If the ceiling in this auditorium were covered with acoustical tile, by how much would the reverberation time be decreased?
5. Specify reasonable values for the reverberation times at 100, 200, 500, and 1000 Hz for a 2000-m^3 concert hall to be used primarily for orchestral music.
6. If two hard parallel walls are spaced 30 m apart, calculate the repetition rate of the flutter echo that might result. What efforts might be made to prevent its occurrence?
7. Repeat a historic experiment done by Joseph Henry more than 130 years ago. Clap your hands periodically as you move away from a large, flat wall. Determine how far away you have to be in order to distinguish the echo from the original sound. Divide twice this distance by the speed of sound to obtain the "limit of perceptibility," as Henry called it [see *J. Acoust. Soc. Am.* **61** 250 (1977)]. Compare your result to that given in Section 23.3.
8. Find the reverberation time at 8000 Hz for a very live room having a volume of 1000 m^3 when the temperature is 20°C and the relative humidity is 30%. Assume that absorption by the walls is negligibly small. Would your answer be different if $V = 100\ \text{m}^3$ instead?
9. Show that in a free field, a graph of L_p versus $\log r$ is a straight line having a slope of −20 (see Fig. 23.1).

EXPERIMENTS FOR HOME, LABORATORY, AND CLASSROOM DEMONSTRATION

Home and Classroom Demonstration Experiments

1. *Resolving time of echoes* Clap your hands as you move away from a large, flat wall on a building. Note the minimum distance away from the wall at which you can distinguish the echo from the original sound. Find the echo-resolving time of your ears by dividing the distance the sound traveled by the speed of sound (see *The Physics Teacher* **16**: 600 (1978)).