9.91 Problems

for Section 9.1,

9-1: In .50 second, 20 wave crests pass your position. What is the wave's speed?

9-2: All radio waves travel at 3×10^8 m/s. The frequency range of AM radio is 550 kHz to 1600 kHz; FM radio is 88 MHz to 108 MHz. Does AM or FM have a longer wavelength? What are the shortest and longest wavelengths for AM waves?

9-3: If the 1.7 m rope, whose mass is 340 g, is struck at "a", how long will it take before a wave pulse reaches "b"?

9-4: Show that "$v = \sqrt{F_T / (m/L)}$" is a dimensionally-correct equation.

9-5: **Surfing**. Do you think water waves will carry a surfboard forward when it is in deep water? When it is in shallow water where the waves are "breaking"?
How could you use a deep-water surfboard to harness some of the wave's energy?

for Section 9.2,

9-6: Both of these strings are identical.
Find the unknown frequency.

In the first picture, what is the number of nodes & antinodes? Compare these with "n".

9-7: In what ways does a loud low tuba note differ from a quiet high violin note?

9-8: Orchestras usually tune to an A-note with a frequency of 440 cycles/s. What are the frequencies of the first 3 overtones?
If the A-string tension is decreased by 6%, what is its frequency? By how much should a violinist shorten the length of a 32.8 cm A-string to make its pitch be 440 Hz again?

9-9: A tone has successive overtones of 240 & 320 Hz. What is the "fundamental"?

9-10: To change a guitar note from A (with f = 110 Hz) to A# (f = 116.5 Hz), what changes could you make. { Hint: $f = (\frac{1}{2}\ n / L)\sqrt{F_T / (m/L)}$. }
A 90 cm guitar string has a mass of 3.6 g. When this string is on the guitar, only 65 cm of it is free to vibrate between its fixed ends. If the string produces a tone of 320 Hz, what force is being exerted on each end?

9-11: **Superposition**
Show the resultant wave that is produced, at the 3 times shown, by these square and triangular waves moving → and ←:

9-12 optional: **Open or Closed Pipes**
Derive a formula that relates f, n, L and v for an open pipe, and for a pipe that is closed on one end and open on the other.
On a 15°C day when the speed of sound is 340 m/s, an open pipe emits a tone of 280 Hz. What is the pipe's length? If one end of the pipe is then closed, what is the lowest tone it can produce?

9-13 optional: **Beats**
When a 440 Hz tone and a guitar tone are played together, a beat tone of 2 Hz occurs. What can you say about the guitar tone?
When the tension of the guitar string is increased slightly, the beat becomes 3 Hz. What was the original guitar frequency?

for Section 9.3,

9-14: What light, sound and bullet speed is measured by each observer? { The gun shoots bullets at 240 m/s. The air temperature is 15°C. }

9-15: How long does it take light to travel the 1.50×10^8 km between the sun and earth?
How quickly can light travel travel from London to New York, 3440 miles (5540 km) across the Atlantic Ocean?
You see lightning and, 5.0 seconds later, hear thunder. How far away was the lightning-and-thunder?
You are at the finish line of a 100 m race. To record an accurate time, should you start your stopwatch when you see the light and smoke from the starter's gun, or when you hear its explosion? If you make the wrong decision and get a race time of 10.15 seconds, what is the correct time?

9-16: "Middle C" has a frequency of 262 cycles/s. What is its wavelength?

9-17: The speed of sound in air changes by approximately .60 m/s for every 1°C change in temperature; as T increases, so does speed. Sound travels 340 m/s in 15°C air. What is its speed at 0°C and at 20°C?

for Section 9.4,

9-18: You move toward a violinist at 10 m/s and hear a tone of 452 Hz. To tune her violin to A_{440} should the musician tighten the string, loosen it, or leave it alone? Assume that she is at rest.

9-19: If you want to hear a 440 Hz A-note as a 495 Hz B-note, how fast must you move?

If the music is moving fast enough to turn A into B, what is its speed and direction?

9-20: As a car passes you it honks a 300 Hz horn. After .90 second you hear a 325 Hz echo from a cliff. How far away is the cliff, and how fast is the car?

9-21: A 40 m/s police car chases you from behind. Your speed is 30 m/s. If the siren is 400 Hz, what frequency do you hear?

The police car passes you and continues onward. If both of your speeds remain the same, what do you hear now? { Besides your own sigh of relief. }

9-22: You drive toward a wall at 20 m/s and play a 300 Hz trumpet call. Charge!! What echo-frequency will you hear?

What do you hear if your call reflects from a 25 m/s car moving away from you?

9-23: A source "•" emits 57 sound waves per second. It is an 18° C day and the wave speed is 342 m/s. The A, B & C waves were emitted 1/57 second apart. The A-wave was emitted first so it has moved the furthest outward, both ← and →. The source is at rest and each observer moves → at 114 m/s, 1/3 of the sound speed. Use visual logic (hint: what is λ?) and "v = f λ" to find the f measured by each observer. Does it agree with the f predicted by the Doppler formula?

----------------- ok?

In the picture below the source moves → at 114 m/s, and the sound speed is 342 m/s. A wave peak is emitted at intervals of 1/57 second, at the •-locations marked a, b, c & d that are (1/57 s)(114 m/s) = 2 m apart. It has been 3/57 second since A was emitted at "a", so A has traveled (3/57 s)(342 m/s) = 18 m in the ← and → directions. At the time of this picture the B & C waves have been traveling 2/57 & 1/57 second, and have moved 12 & 6 m. { To convince yourself that the picture is accurate, count the distance A, B & C have moved away from a, b & c. Each square is 2 m. This picture is taken at the instant the D-peak is emitted at d. } Use visual logic (hint: what is λ in each direction?) and "v = f λ" to find the f seen by each stationary observer. Does this agree with the f that is calculated by the Doppler formula?

9-24: On a windless day, you hear a 440 Hz horn at 587 Hz, because you and the horn are moving with a relative velocity of 85 m/s. Who is moving, you or the horn?

If you and the horn are moving toward each other at 42.5 m/s, what will you hear?

9-25: **The Relativity Principle**

If there is wind, you can use this formula:

$$f_{observed} = f_{source} \frac{-v_{wind} + v_{sound} + v_{observer}}{-v_{wind} + v_{sound} - v_{source}}$$

where v_{wind}, $v_{observer}$ and v_{source} are the velocities of wind, observer and source with respect to the ground, and v_{sound} is the speed of sound in still air.

Show that, when $v_{wind} = 0$, this formula is the same as the shift-formula in Section 9.4. { Hint: Cleverly multiply part of the equation by "1". }

In Problem 9-## the horn is moving away from you. But if you see the horn move ← at 85 m/s, it sees you moving → at 85 m/s, and a wind blowing → at 85 m/s. Show that you can explain the Doppler frequency-shift (440 Hz becomes 587 Hz) using the formula above, and thus cannot tell who is "really" moving.

for Section 9.5,

9-26: During each second, a wave carries .45 Joule of energy through a 3 m x 3 m square. What is the wave's intensity?

During a 30 second interval, a wave carries 1.50 Joules of energy through a 1 m^2 area. What is the wave's intensity?

9-27: The power carried by a vibrating string-wave is proportional to $(\text{amplitude})^2$, (mass/length), (velocity) and $(\text{frequency})^2$: $P \propto (y_{max})^2$, $P \propto (m/L)$, $P \propto v$, and $P \propto f^2$, or $P = (\text{a constant})\,(y_{max})^2\,(m/L)\, v\, f^2$.

What happens to a string-wave's power if each factor (y_{max}, m/L, v, f) is doubled while the other 3 factors remain constant?

9-28: A light bulb is at the center of a sphere (6.0 m diameter). If the intensity at the sphere's surface is .54 W/m^2, what is the power output of the bulb?
Using the same bulb, what is the radius of a sphere with an intensity of 1.08 W/m^2?

9-29: What is the intensity of a 45 dB sound? What is the intensity level if the sound intensity increases by a factor of 1000? if it increases by a factor of 500? if it decreases by a factor of 1/4?

9-30: What is the intensity level of a sound wave that is 7.5 x 10^{-5} W/m^2?

9-31: What is the intensity ratio of sounds that are 115 dB and 72 decibels?

9-32: If a sound changes from 60 dB to 90 dB, what is its change of intensity, intensity level, and loudness?
{ Assume that loudness doubles when I increases by a factor of 10. }

9-33: Two sounds, 50 dB and 60 dB are played together. What total intensity level do they produce?

9-34: One mosquito buzzing 10 m away produces an intensity of approximately 10^{-12} W/m^2, at about the "threshold" of human hearing sensitivity. What intensity level is produced by 200 mosquitoes at 10 m?
If 4 simultaneous firecrackers produce 100 dB, what will 1 firecracker produce?

9-35: If the sound level 30 m from a jet plane is 140 dB, at what distance is it 100 dB?
Air absorbs sound at a rate of 7 dB/km. When this is taken into account, what is the expected intensity level 3 km from the jet?

9-36: **Tape versus Compact Disc**.
Compare the loudness of the "noise" for CD, Dolby tape and non-Dolby tape if the signal-to-noise ratios are 95 dB, 70 dB and 50 dB, respectively.

==[put this in a 9-# solution?] ==[probably keep it with 9-C where it is now]
Always check whether your answer is reasonable, in case you use "log" when you should use "10^x", or vice versa. For example, if you punch " 100 10^x " and get 100000, common sense should tell you that 100000 is too large to be decibels or a decibel difference. A multiplying factor could be this large, but the multiplying factor was "given" as 5, so it can't be 10^5.

9.92 Solutions

9-1: The wave's frequency is 20 cycles/.50 second = 40 cycles/s, its wavelength (distance between peaks) is .24 meter/cycle, and its speed is

$$\mathbf{v = f\lambda} = (40 \text{ cycles/s}) (.24 \text{ m/cycle}) = .96 \text{ m/s}$$

9-2: v = fλ, and both waves have the same speed, so λ is large when f is small. All AM waves (550 x 10^3 Hz to 1600 x 10^3 Hz) have lower frequency than FM waves (88 x 10^6 Hz to 106 x 10^6 Hz), so AM waves have longer λ. AM-radio wavelengths vary from λ = v/λ = (3 x 10^8 m/s) / (550 x 10^3) = 545 m, to (3 x 10^8 m/s) / (1600 x 10^3) = 187 m.
Unit-prefixes are discussed in Section 1.6.

9-3: The 40 kg mass produces a tension of 392 N.

$$v = \sqrt{\frac{F_T}{m / L}} = \sqrt{\frac{392}{.340 / 1.7}} = 44 \text{ m/s}$$

9-4: Substitute SI units; both sides are m/s. OK.

$$v = \sqrt{\frac{F_T}{m / L}}$$

$$\text{m/s} = \sqrt{\frac{\text{kg m / s}^2}{\text{kg / m}}}$$

9-5: In deep water, a surfboard rides up and down on the waves but doesn't move forward. In shallow water, when interaction with the bottom causes waves to "break" (this is a very unusual type of wave behavior), a wave can carry a surfboard forward.
The surfboard's up-and-down motion is analogous to the piston in a car engine. Its kinetic energy could be harnessed in a similar way, by using it to turn the shaft of a motor, an electric generator, or...

9-6: The frequency of the n=2 mode [right-side picture] is 2/3 that of the n=3 mode [left-side picture]: $f_{2\text{-mode}}$ = (540 Hz) (2/3) = 360 Hz.
There are 4 nodes: two at the ends, two in-between. The number of half-wavelengths (3) and antinodes (3) equals the n-number.

9-7: Loud-quiet: the notes differ in *amplitude* and also, as explained in Section 9.5, *power & intensity.* Low-high indicates their *pitch* difference. The notes also differ in *quality* (the relative loudness of their overtones) and, of course, in the "musical effect" that is perceived by a listener.

9-8: The "fundamental" has n = 1. The frequency of the first three overtones (with n = 2, 3 & 4) are multiplied by factors of 2, 3 & 4, so they are 880 Hz, 1320 Hz & 1760 Hz.
When F_T decreases by 6% it is multiplied by .94. f is proportional to $\sqrt{F_T}$, so f changes by a factor of $\sqrt{.96}$ = .970; the new f is (440 Hz)(.970) = 427 Hz.

The string tension m/L stays constant, so $f \propto 1/L$ and must shorten (to increase pitch to 440 Hz) by a factor of .970. The new length is (32.8 cm)(.970) = 31.8 cm. To answer the question: the string must be shortened by "32.8 – 31.8" = 1.0 cm.

9-9: Successive overtones differ by 80 Hz, so you can "count backwards", 320 240 160 80, until you reach the fundamental (n = 1) frequency of 80 Hz.

9-10: Use ratio logic. f increases by a multiplying factor of 116.5/110 = 1.059. This could be done by changing L, F_T or m/L. Proportionalities are: $f \propto 1/L$, $f \propto \sqrt{F_T}$, $f \propto \sqrt{1/(m/L)}$. If you change one factor while the others remain constant, you could decrease L by a multiplying factor of 1/1.059 = .944, increase F_T by a factor of $\sqrt{1.059} = 1.029$, or decrease m/L by a factor of $\sqrt{1/1.059} = .972$.

Substitute: $320 = [\frac{1}{2}(1)/(.65)]\sqrt{F_T/(.0036/.90)}$. Then square both sides of the equation (do the algebra yourself) and solve for F_T = 450 N. This tension force pulls equally on each end of the string.

9-11: Find the superposition result at the locations marked "•", then figure out what happens in-between:

9-12: The guitar tone could be 338 Hz or 442 Hz. Either frequency would, when interacting with a tone of 440 Hz, produce a beat of 2 Hz.

When tension increases, guitar tone frequency also increases. If it changes from 442 Hz to 443 Hz, the beat frequency is "443 – 440 = 3 Hz" (as observed). But if it was 338 Hz and increased to 339 Hz, the beat would decrease to 1 Hz (not observed). Do you see why this shows that the original tone was 442 Hz?

9-13: As in 9.2, substitute $v/f = \lambda$ and rearrange.

$L = n(\frac{1}{2}\ \lambda)$	$L = (2n+1)(\frac{1}{2}\ \lambda)$
$L = n(\frac{1}{2}\ v/f)$	$L = (2n+1)(\frac{1}{4}\ v/f)$
$f = \frac{1}{2}\ [n/L]\, v$	$f = \frac{1}{2}\ [(2n+1)/L]\, v$

Substitute: $280 = \frac{1}{2}(1/L)(340)$. Solve: L = .61 m.

If one end of the pipe is closed, the lowest tone (with n = 0) has $f = \frac{1}{4}\ [(2(0)+1)/(.61)]\,(340) = 140$ Hz, half of the open pipe frequency.

9-14: Use the principles from Section 9.3. Both observers see the light move at +299,709,080 m/s. The left-side observer sees sound travel ← at 400 m/s (it travels 340 m/s with respect to air, and he moves toward it at an "extra" 60 m/s), and the bullet moves ← at 300 m/s (= 240 + 60). The other observer sees sound and bullet move → toward him at 280 m/s and 180 m/s (= 240 – 60), respectively.

9-15: Rearrange "$\Delta x = v\,\Delta t$" to get "$\Delta x/v = \Delta t$". $\Delta t = (1.50 \times 10^8 \times 10^3\ m)/(3.00 \times 10^8\ m/s) = 500$ s = 8 minutes and 20 seconds.

• Light would make a quick trans-Atlantic crossing, $\Delta t = (5540 \times 10^3\ m)/(3.00 \times 10^8\ m/s) = .018$ s, but there is one difficulty. Because the earth is curved the light will go "off into space", not into Manhattan.

• Lightning & thunder are produced simultaneously. We hear thunder after seeing lightning because sound travels more slowly and takes longer to reach you. To find Δx, set up an equation based on the fact that 5.0 s is the <u>difference</u> between sound-time and light-time:

$$\Delta t = \Delta t_{sound} - \Delta t_{light}$$

$$5.0\ s = \frac{\Delta x}{v_{sound}} - \frac{\Delta x}{v_{light}}$$

$$5.0 = \frac{\Delta x}{340} - \frac{\Delta x}{3 \times 10^8}$$

$$5.0 = \frac{\Delta x}{340} - 0$$

$$1700\ m = \Delta x$$

It takes only .018 s for light to cross the Atlantic, so we conclude that lightning-light reaches us almost instantly: $\Delta x/v_{light} \approx 0$. The Δt of 5.0 s is essentially the time it takes for thunder-sound to reach you.

• The starter's gun is analogous to lightning-thunder. You should start your watch when you see the flash from the gun. If you wait for the sound to reach you, you'll start your watch late by $\Delta t = \Delta x/v = 100/340 = .29$ s, and measure a race time that is too short. The correct time would be (10.15) + (.29) = 10.44 s.

9-16: $\lambda = v/f = (340\ m/s)/(262\ m) = 1.30$ m.

9-17: At 0°C, sound speed = 340 – (15° – 0°)(.60) = 340 – 9.0 = 331 m/s.

At 20°C, v_{sound} = 340 + (20° – 15°)(.60) = 343 m/s.

9-18: $f_{observed}$ is 450 Hz, $v_{observer}$ is +20 m/s, the violin (the source) is at rest. We want to find f_{source}:

$$452 = f_{source}\ \frac{1 + (+10)/340}{1 - 0/340}$$

f_{source} = 452/(1.0294) = 439 Hz. The violin note is "flat" (it is below the tuning goal of 440 Hz) so the string should be tightened slightly.

9-19: For either situation, $f_{observed}$ = 495 Hz and f_{source} = 440 Hz. It is more complicated to solve for v than for f, but it isn't difficult; use basic principles and make progress one easy step at a time. In these algebra summaries, some steps have been skipped (so to understand the algebra, do them for yourself):

If you are moving and $v_{source} = 0$,	If the source is moving and $v_{observer} = 0$,
$495 = 440 \dfrac{1+v_o/340}{1-0/340}$	$495 = 440 \dfrac{1+0/340}{1-v_s/340}$
$1.125 = 1 + .00294\, v_o$	$1 - .00294\, v_s = .8889$
$42.5 \text{ m/s} = v_{observer}$	$37.8 \text{ m/s} = v_{source}$

9-20: The sound travels a distance of $\Delta x = v\Delta t$ = (340)(1.20) = 408 m for the "round trip"; sound goes to the cliff, reflects and comes back. The distance to the cliff is only $\frac{1}{2}$(408 m) = 204 m.

Substitute and calculate v_{source} as in Problem 9-##: $325 = 300[(1+0) / (1 - v_s / 340)]$, v_{source} = 26.2 m/s.

Optional "check": $f_{obs} = 300[1/(1 - 26.2/340) = 325$ Hz, just as it should be.

9-21: The police car moves toward you (v_{source} = +40) but you move away from him ($v_{observer}$ = –30). Later, he moves away (–40) but you move toward him (+30). Now substitute and solve.

$$\text{Early: } f_{obs} = 400 \frac{1+[-30]/340}{1-[+40]/340} = 413 \text{ Hz.}$$

$$\text{Later: } f_{obs} = 400 \frac{1+[+30]/340}{1-[-40]/340} = 389 \text{ Hz.}$$

9-22: The wall "hears" a +20 m/s source emit a 300 Hz tone: $f_{obs} = 300[(1+0)/(1–20/340)] = 319$ Hz.
This tone reflects and you (a +20 m/s observer) hear it: $f_{obs} = 319[(1+20/340)/(1–0)] = 338$ Hz.

The other car is a –25 m/s observer (moving away from you, the source) and you are a +20 m/s source (moving toward the other car, the observer), so

$$f_{obs} = 300 \frac{1 + (-25)/340}{1 - (+20)/340} = 295.313 \text{ Hz.}$$

Even though the other car is moving, the 295.313 Hz tone reflects with unchanged frequency. The other car is a 25 m/s "reflecting source", and you are now a +20 m/s observe moving toward this source:

$$f_{obs} = 295.313 \frac{1 + (+20)/340}{1 - (-25)/340} = 291.267 \text{ Hz.}$$

Optional: The cars' relative velocity of 5 m/s can be used to construct a simplified situation that is similar to, but not the same as, the problem situation: imagine that you are a –5 m/s source (in the first interaction) <u>and</u> a –5 m/s observer (in the second interaction):

$$f_{obs} = 300 \frac{1 + (-5)/340}{1 - (-5)/340} = 291.304 \text{ Hz}$$

This quick shortcut gives a result that is almost the same, but not identical.

9-23: The distance between the A & B (or B & C) peaks is given, on the picture, as 6 m. The relative speeds of the left & right observers are "114 + 342 = 456 m/s" and "342 – 114 = 228 m/s". Substitute into the formula, $v = f\lambda$ or Doppler, and solve for $f_{observed}$:

For the left observer,	For the right observer,
$v = f\ \lambda$	$v = f\ \lambda$
$456 = f\ 6$	$228 = f\ 6$
$76 \text{ Hz} = f$	$38 \text{ Hz} = f$
$f_{obs} = 57 \dfrac{1+(+114)/342}{1 - 0/342}$	$f_{obs} = 57 \dfrac{1+(-114)/342}{1- 0/342}$
f_{obs} = 76 cycles/s	f_{obs} = 38 cycles/s

As expected, "visual logic with $v=f\lambda$" and the Doppler formula predict the same results.

Look at the second picture [with a moving source] and notice that the distance between successive peaks (A, B, C, D) peaks that move ← is 8 m; this is λ. But there is less distance between the peaks that move →; their λ is 4 m. As above, substitute and solve:

For the left observer,	For the right observer,
$v = f\ \lambda$	$v = f\ \lambda$
$342 = f\ 8$	$342 = f\ 4$
$42.75 \text{ Hz} = f$	$85.5 \text{ Hz} = f$
$f_{obs} = 57 \dfrac{1 + 0/342}{1-(-114)/342}$	$f_{obs} = 57 \dfrac{1+ 0/342}{1-(+114)/342}$
f_{obs} = 42.75 cycles/s	f_{obs} = 85.5 cycles/s

Again, both methods predict the same result!

I hope this visual-math derivation helps you understand the Doppler shift at a deeper level, so you're not just "plugging numbers into an equation".

9-24: Calculate $f_{observed}$ for both possibilities.

If the horn is moving,	If you are moving,
$f_{obs} = 440 \dfrac{1+0/340}{1-85/340}$	$f_{obs} = 440 \dfrac{1+85/340}{1-0/340}$
f_{obs} = 587 Hz (OK!)	f_{obs} = 550 Hz (wrong)

Under the stated conditions, that there is no wind, we can conclude that the horn is moving.

If you and horn both moved at 42.5 m/s you would hear $f = 440(1 + 42.5/340)/(1 - 42.5/340) = 566$ Hz.

9-25: If you substitute "$v_{wind} = 0$" and multiply the fraction's top & bottom by $1/v_{sound}$ (do you see why this multiplies the right side by "1" and is thus an acceptable algebraic operation?) you'll get the same equation as in Section 9.4. Try it and see!

In a reference frame where the horn at rest, it sees the wind and you both coming toward it, so v_{wind} and $v_{observer}$ have a ± sign that is +. v_{sound} is a speed; it is a magnitude (so it is always +) and has no ± sign.

$$f_{observed} = f_{source} \frac{-v_{wind} + v_{sound} + v_{observer}}{-v_{wind} + v_{sound} - v_{source}}$$

$$f_{observed} = (440) \frac{-(+85) + (340) + (+85)}{-(+85) + (340) - (0)}$$

$$f_{obs} = 440 \frac{340}{255} = 587 \text{ Hz (the same as before!)}$$

$f_{observed}$ is 587 Hz whether we consider you (and the ground) to be at rest, or the horn to be at rest. This illustrates the *principle of special relativity* that is discussed in Chapter 16: **the laws of physics are the same in all constant-velocity reference frames, and there is no experiment that can detect "absolute" constant-velocity motion**.

9-26: Intensity = (.45 J/s) / (9 m^2) = .05 W/m^2. This illustrates the concept of intensity as "energy-per-second per square meter".

Intensity = (1.50 J/m^2) / (30 s) = .05 W/m^2. This shows intensity as "energy-per-m^2 per second".

Do you see how these two concepts are equivalent, yet lead to different "mental pictures" of intensity?

9-27: If the amplitude of a string-wave doubles, its energy & power are multiplied by $(2)^2 = 4$. If a heavier string is used and the string's mass/length ratio doubles, the wave-power also doubles. If wave speed doubles, power carried by the wave doubles. And if wave frequency doubles, the wave's power is multiplied by $(2)^2 = 4$.

9-28: The sphere's surface area is $4\pi r^2 = 4\pi(3.0)^2 = 113.1\ m^2$. P = (.54 W/m^2)(113.1 m^2) = 61 Watts.

To answer the second question, you can substitute into P = IA: (61) = (1.08)($4\pi r^2$), so r = 2.12 m.

Or use ratio logic: I doubles (from .54 to 1.08) if A is halved, which occurs when r decreases by a factor of $1/\sqrt{2}$ = .707. The new r is (.707)(3.0) = 2.12 m.

9-29: Intensity = $I_o\ 10^{45/10} = 10^{-12}$ (31622) = $3.16 \times 10^{-8}\ W/m^2$.

If I increases by a factor of 1000, I-level increases by 10(log 1000) = 10(3), from 45 dB to 75 dB.

If I increases by a factor of 500, I-level increases by 10(log 500) = 10(2.7) = 27, to 72 dB.

If I decreases by a factor of 1/4 = .25, the I-level decreases by 10(log .25) = –6, to 39 dB.

9-30: $\beta = 10 \log[(7.5 \times 10^{-5})/(1 \times 10^{-12})] = 79$ dB.

9-31: Use either method shown in Problem 9-C. I prefer an "intuitive" strategy; the decibel difference is 115 – 72 = 43, which corresponds to an intensity ratio of $10^{43/10} = 10^{4.3} = 2.0 \times 10^4$.

9-32: Intensity changes by a factor of $10^{(90-60)/10} = 10^3 = 1000$. Or you could say that I increases from $10^{-12}\ 10^{6.0}$ to $10^{-12}\ 10^{9.0}$ (from $.001 \times 10^{-3}$ to 1.000×10^{-3}), a difference of $.999 \times 10^{-3}\ W/m^2$.

The intensity level increases by 30 dB.

Loudness doubles once for each 10 dB increase in I-level, once from 60 dB to 70 dB, again from 70 dB to 80 dB, and also from 80 dB to 90 dB, so the overall change in loudness is 2 x 2 x 2 = 8. In a formula: loudness change = $2^{(\text{dB change})/10}$.

Bonus: Derive the analogous formula for loudness change if we assume that loudness doubles when I increases by a factor of 8. {Answer is after 9-##.}

9-33: Because intensity levels are "logarithmic", they are not additive; the answer is not "110".

But you can add intensities:
$I_{total} = I_{50} + I_{60} = (10^{-12}\ 10^{5.0}) + (10^{-12}\ 10^{6.0}) = 10^{-12} [(.1 \times 10^6) + (1.0 \times 10^6)] = 10^{-12} (1.1 \times 10^6) = 10^{-12}\ 10^{6.04}$. The total intensity level is only 60.4 dB. Do you find it surprising that the 50 dB sound made such a small difference in the overall intensity level?

(9-32) If I ↑ by a factor of 8, I-level ↑ by 10(log 8) = 9.0. To find the number of doublings, divide the dB change by 9: loudness change = $2^{(\text{dB change})/9}$.

9-34: 500 mosquitoes produce 500 times the I of one mosquito: I = 200(10^{-12}) = $10^{2.3}\ 10^{-12}$, thus producing 23 dB.

As in 9-##, you can add I's but not I-levels. Four firecrackers cause I = $10^{-12}(10^{10.0}) = 10^{-12}(1 \times 10^{10})$, so one causes I = $10^{-12}(.25 \times 10^{10}) = 10^{-12}(10^{9.4})$. Each firecracker produces 94 dB.

9-35: Use ratio logic. $I \propto A$. If we assume that spherical "inverse square logic" can be used, $I \propto 1/r^2$. To make I decrease by a factor of $10^{(140-100)/10} = 10^4$, A and r must increase by factors of 10^4 and 10^2, respectively, so r = 10^2 (30) = 3000 m = 3 km.

From 90 m to 3000 m is 2910 m = 2.91 km, so air absorbs (7 dB/km)(2.91 km) = 20 dB. As calculated above, when r ↑ by a factor of 3000/30 = x10^2, A ↑ by x10^4, I ↓ by x10^4, and I-level ↓ by 40 dB. At 3 km the I-level is 140 – 20 – 40 = 80 dB.

9-36: The noise (hiss,...) is $1/10^{9.5}$, $1/10^{7.0}$ and $1/10^{5.0}$ times as intense as the signal (music!). You hear the least noise with CD, $10^{2.5}$ more noise with Dolby tape, and $10^{4.5}$ more with non-Dolby tape. As shown in Problem 9-#1, this corresponds to relative loudnesses of 1, $2^{2.5} = 5.7$, and $2^{4.5} = 22.6$, ==[ok? nec?] if the amplifier doesn't introduce any "extra noise".