MT1 Physics 1B-3, S15

Full Name (Printed) [redacted]

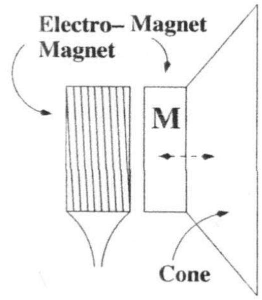
Full Name (Signature) [redacted]

Student ID Number ______________________

Seat Number ______________________

Problem	Grade
1	17 /30
2	22/30
3	25 /30
Total	64 /90

- Do not peek at the exam until you are told to begin. You will have approximately 50 minutes to complete the exam.
- Don't spend too much time on any one problem. Solve 'easy' problems first. Go for partial credit!
- **HINT:** Focus on the concepts involved in the problem, the tools to be used, and the set-up. If you get these right, all that's left is algebra.
- **Have Fun!**



The diagram above shows a very simple loudspeaker. The main part consists of a magnet (mass M) attached to a flexible cone. The speaker is designed so that, in proper use, as the magnet is displaced slightly (left or right) from it's equilibrium position, the cone will push or pull on it with a linear restoring force.

On the left side of the diagram is an electromagnet. When electric current is driven through the electromagnet, it creates a magnetic field that can be used to drive the magnet and cone back and forth (creating sound). When the current is shut off, the electromagnet does nothing.

Initially, the current is shut off. The magnet is displaced slightly, and released, and the magnet/cone system is observed to oscillate back and forth with a frequency f (cycles/second). The energy of the magnet cone system is observed to drop from E_0 to FE_0 ($F < 1$) in N complete cycles.

- 1a) (10 points) What is the natural frequency of the mass/spring system? [You may answer this in terms of frequency, f_0, or angular frequency, ω_0, - just be clear.]

Let the damp force be $-bv$

$$\omega = 2\pi f = \sqrt{\omega_0^2 - \left(\frac{b}{2m}\right)^2}$$

$T = \frac{1}{f}$

$$\omega_0^2 = \omega^2 + \left(\frac{b}{2m}\right)^2$$

$$\omega_0 = \sqrt{\omega^2 + \left(\frac{b}{2m}\right)^2} = \sqrt{4\pi^2 f^2 + \left(\frac{b}{2m}\right)^2}$$

In N complete cycles, the damp force consumed the energy by $(1-F)E_0$

the amplitude A' at this time is

$$\frac{1}{2}kA'^2 = (1-F)\frac{1}{2}kA_0^2$$ original amplitude

$$A' = \sqrt{1-F}\,A = Ae^{-\frac{bt}{2m}}$$
$$= Ae^{-\frac{b\frac{N}{f}}{2m}}$$

+ 8

$$\sqrt{1-F} = e^{-\frac{bN}{2mf}} \qquad b = \ln\left(\frac{1}{\sqrt{1-F}}\right)^{\frac{2mf}{N}}$$

$$\frac{bN}{2mf} = \ln\left|\frac{1}{\sqrt{1-F}}\right| \qquad \omega_0 = \sqrt{4\pi^2 f^2 + \left(\frac{\ln(\sqrt{1-F})^{-\frac{2mf}{N}}}{2m}\right)^2}$$

- 1b) (5 points) What is the effective "spring constant" of the cone?

$$E_0 = \frac{1}{2} k A^2$$

$$k = \frac{2E_0}{A^2}$$

- 1c) (10 points) Suppose we connect the electromagnet to a source of sinusoidally-varying electric current. Assuming the electromagnet then exerts a sinusoidally-varying force (of amplitude F_0, and same frequency as the varying electric current) on the magnet, at what frequency of the driving current will the speaker take on the largest-amplitude vibrations?

$$\Omega_{res} = \sqrt{\omega_0^2 - 2\left(\frac{b}{2m}\right)^2}$$

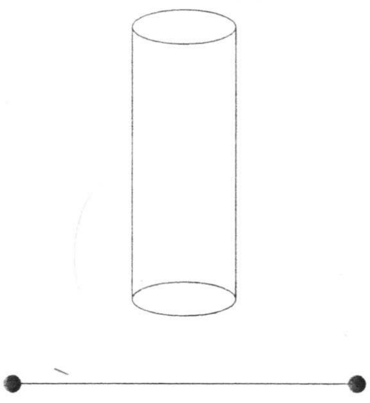
$$= \sqrt{\omega^2 + \left(\frac{b}{2m}\right)^2 - 2\left(\frac{b}{2m}\right)^2}$$

$$= \sqrt{\underbrace{\omega^2}_{2\pi f} - \left(\frac{\ln\sqrt{1-F}^{\,-\frac{2mf}{\pi}}}{2m}\right)^2}$$

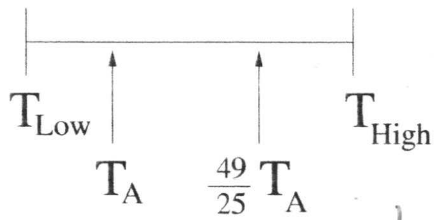
+ 9

- 1d) (5 points) Under normal circumstances, F_0 has to be set large enough so that you can actually hear the sound coming out of the speaker. Describe a couple of (detrimental) things that might happen if the driver is set for "normal" values of F_0, at the frequency determined in part c.

If the damp force is small, ~~there~~ might be loud sharp sound coming out



m, L_1



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In the apparatus shown, the string (fixed at both ends and driven in its fundamental mode) is used to search for resonant frequencies in the neighboring tube. As the tension in the string is varied from T_{low} to T_{high}, the tube is found to resonate at precisely two settings: T_A and $\frac{49}{25}T_A$. For the following, you may assume that the string has a mass m and length L_1, and you may take the speed of sound in air to be v_{snd}...

- 2a) (10 points) Is the tube open on both ends, or just one? [your answer will be judged by the quality of the argument you use to support it].

$$f_1 = \frac{V_{s1}}{2L_1} = \sqrt{\frac{T_A L_1}{m}} \cdot \frac{1}{2L}$$

$$f_2 = \frac{V_{s2}}{2L_1} = \sqrt{\frac{49}{25}\frac{L_1}{m}} \quad \frac{1}{2L} = \frac{7}{5} f_1$$

The tube is open on just one ends.

The two harmonics should be next to each other.

If both ends are open, there should be an even-number frequency between the two.

- 2b) (10 points) What is the frequency of the fundamental mode in the tube? Which harmonic does the string excite in the tube when $T = T_A$?

$$f = \frac{V_x}{4L} \cdot N$$

$$f = \frac{1}{5} f_1 = \sqrt{\frac{T_A L_1}{m}} \cdot \frac{1}{2L}$$

When $T = T_A$, it is the 5th harmonic.

- 2c) (5 points) How long is the tube?

$N = 1 \quad 2 \quad 3$

$f \quad 3f \quad 5f$

$$f = \frac{V_{snd}}{4L} \cdot 3 = \sqrt{\frac{T_A L_1}{m}} \cdot \frac{1}{2L_1}$$

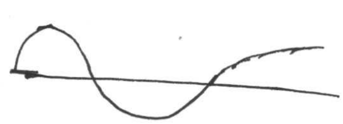
X -3

$$\cancel{f = \frac{V_{snd}}{4L} \cdot 5 = \sqrt{\frac{T_A}{m}} \cdot \frac{5}{4L}}$$

$$f = \frac{V_{snd}}{\cancel{4L}} \cdot 5 = \sqrt{\frac{T_A L_1}{m}} \cdot \frac{2L}{8L_1}$$

$$L = \frac{5}{2} V_{snd} \cdot \sqrt{\frac{m L_1}{T_A}} = \frac{5}{2} V_{snd} \sqrt{\frac{m L_1}{T}}$$

- 2d) (5 points) Sketch the waveform corresponding to the lower of the two resonant frequencies in the tube. Label the ends as open and/or closed, and be clear whether the waveform you sketch describes displacement of the medium or pressure.



X -5

Having nothing better to do on a beautiful Saturday afternoon, you find yourself at a racetrack watching one of the cars doing test laps around the oval. As the car approaches you, you note that the whine you hear from the engine has a frequency of F_{app}, after it has passed, you note the frequency has changed to F_{dep}.

- 4a) (5 points) Which of the given frequencies is larger? Why? Explain how the sound coming from the engine came to be heard at two different frequencies. Note, the name of the effect may buy you a point; I'm really asking you to explain how the effect works in this case.

$F_{app} > F_{dep}$

According to the Doppler effect, when the car approaches the listener, the sound source pushes the crest so the frequency becomes higher (while wave length lower because later crests are pushed so they are nearer to the last crest). ✓

Similarly, when the car leaves, the later crests come out at a larger distance to the listener than a fixed source, and the frequency percepted by the listener is therefore lower ✓

5/5

- 4b) (15 points) How fast is the car moving? (You may take the speed of sound in air to be V_{snd})

Let the original frequency of the whine be f ✓

$$\frac{F_{app}}{f} = \frac{V_{snd}}{V_{snd} - V_{car}}$$ ✓

$$\frac{F_{dep}}{f} = \frac{V_{snd}}{V_{snd} + V_{car}}$$ ✓

$$\frac{F_{app}}{F_{dep}} = \frac{V_{snd}}{V_{snd} - V_{car}} \cdot \frac{V_{snd} + V_{car}}{V_{snd}}$$

$$= \frac{V_{snd} + V_{car}}{V_{snd} - V_{car}}$$

15/15

$$F_{app} V_{snd} - F_{app} V_{car} = F_{dep} V_{snd} + F_{dep} V_{car}$$

$$\boxed{V_{car} = \frac{(F_{app} - F_{dep}) V_{snd}}{F_{app} + F_{dep}}}$$ ✓ very good!

- 4c) (10 points) Show that the frequency emitted by the engine, as heard by the driver is given by...

$$f_{engine} = f_{avg}(1 - \frac{v_{car}^2}{v_{snd}^2}) \quad \text{where} \quad f_{avg} = \frac{f_{app} + f_{dep}}{2}$$

$$\frac{F_{app}}{f} = \frac{V_{snd}}{V_{snd} - V_{car}}$$

$$f = \frac{F_{app}(V_{snd} - V_{car})}{V_{snd}}$$ yes, want to find f +2

$$= \frac{F_{app}}{V} \cdot \left(1 - \frac{F_{app} - F_{dep}}{F_{app} + F_{dep}}\right)$$ want to keep V_{car}, V_{sound} dependence.

$$= f_{app} \cdot \frac{2 f_{dep}}{2 f_{avg}}$$ ✓ +3

$$= \frac{\quad}{2 f_{avg}}$$

$$\frac{V_{car}}{V_{snd}} = \frac{f_{app} - f_{dep}}{2 f_{avg}}$$

$$f_{avg}\left(1 - \frac{(f_{app} - f_{dep})^2}{4 f_{avg}^2}\right) = f_{avg} - \frac{(f_{app} - f_{dep})^2}{4 f_{avg}}$$

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