Physik 1: Wellen und Thermodynamik
Schriftliche Prüfung vom 16.08.2018, 14-16 Uhr

Bitte gut leserlich in Druckschrift ausfüllen

Name:

Vorname:

Legi-Nr.:

- Achten Sie darauf, dass Ihnen **fünf** Aufgaben ausgeteilt wurden. Bitte führen Sie alle Rechnungen und Zwischenrechnungen auf den bereitgestellten Blättern durch. Fünf Zusatzblätter befinden sich am Ende der Prüfungsbögen. Beschriften Sie alle Blätter mit Vor- und Nachnahmen und Leginummer.
- Ergebnisse ohne nachvollziehbare Begründung können nicht gewertet werden. Sämtliche Resultate aus der Vorlesung und den Übungen dürfen als gegeben vorausgesetzt werden und müssen nicht begründet werden. Bei numerischen Ergebnissen genügt eine Genauigkeit von 10%. Numerische Resultate können auch als Bruchzahl dargestellt werden, wobei die Brüche so weit wie möglich zu kürzen sind.
- Erlaubte Hilfsmittel sind eine selbstverfasste Zusammenfassung von 10 Blättern (DIN A4) beidseitig beschrieben (von Hand oder Computerausdruck) sowie ein Fremdwörterlexikon. NICHT erlaubt sind Taschenrechner, Laptops, Mobiltelefone und vergleichbare Geräte.
- Legen Sie Ihre Legi vor sich auf den Tisch. Mobiltelefone müssen ausgeschaltet sein.
- Wir weisen Sie darauf hin, dass Sie im Falle von unehrlichen Handeln bei Prüfungen den Strafnormen der Disziplinarordnung der ETH Zürich unterstehen.

KORREKTUR:

Aufgabe	Punkte	AssistentIn
1	/ 12	
2	/ 12	
3	/ 12	
4	/ 14	
5	/ 10	
Σ	/ 60	

NOTE:

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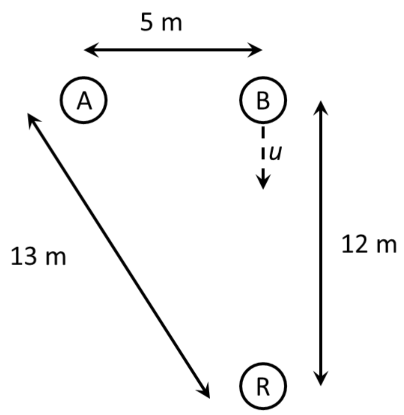
Exercise 1 - Guitarists (12 points)

Two guitarists stand at a distance of 5 m from each other and play their guitars in phase (see figure below). A listener (R) is standing 12 m away from guitarist B and 13 m from guitarist A. The listener perceives the same intensity from the two guitarists. Both guitarist are using $L = 0.5\,\text{m}$ strings with a linear mass density of $\mu = 2\,\frac{\text{g}}{\text{m}}$. Use $v_{sound} = 300\,\frac{\text{m}}{\text{sec}}$ for the speed of sound in air.



a) What are the first three frequencies for constructive interference (at the listener position)? **(2 points)**

b) The listener hears a beating of 10 Hz. The string guitarist A is playing is tuned to 440 Hz.
What is the tension of the string of guitarist B if by increasing the tension the beating frequency increases? **(3 points)**

c) After tuning his guitar to match guitarist A's guitar, guitarist B starts walking toward the listener with a velocity of $u = 3\,\text{m/sec}$. What is the beating frequency that the listener hears now?
Does guitarist B need to tighten or loosen the tension on the string in order to eliminate the beating that the listener perceives? **(4 points)**

d) Before guitarist B starts moving the listener perceives the same intensity from the two guitarists (while separately playing their guitars). What is the intensity ratio, $\frac{I_B}{I_A}$, that the listener perceives after guitarist B advances 6 m? **(3 points)**

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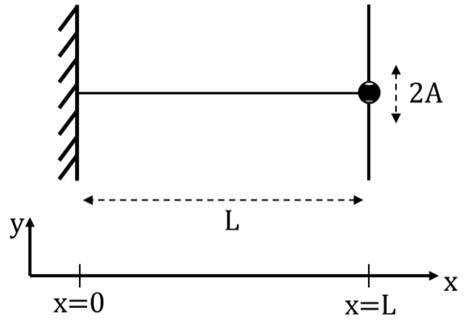
Exercise 2 - Standing waves (12 points)

A string is attached to a wall on one side, while the other side is connected to a bead that is free to move on a pole (see figure below). The bead has negligible mass and there is no friction with the pole. The length of the string is $L = 10\,\mathrm{m}$, the linear mass density is $\mu = 100\,\frac{\mathrm{g}}{\mathrm{m}}$, the tension is $F_T = 10\,\mathrm{N}$, and the oscillation amplitude peak is $A = 10\,\mathrm{cm}$. In this question assume that there is no gravity and that the tension on the string remains constant.



a) What are the frequencies of the first three harmonics? **(4 points)**

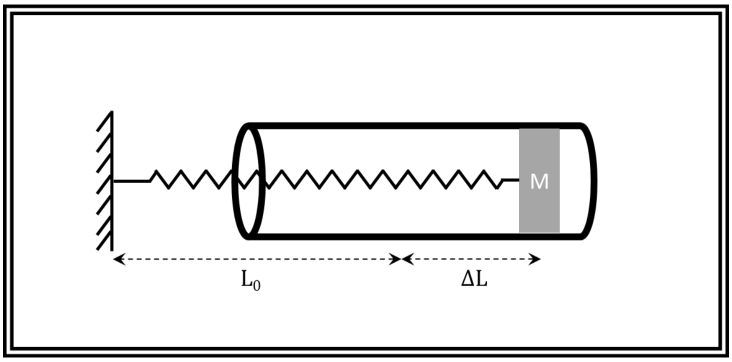
b) At time $t = 0$ the first anti-node is in its maximum displacement in the $+\hat{y}$ direction. Write the fundamental harmonic wave function $y(x, t)$.
Plot the displacement for $\omega t = 0$, $\omega t = \frac{\pi}{2}$ and $\omega t = \pi$. Don't forget to label the axes and use the right units. **(3 points)**

c) Calculate the total energy of the wave (consider only the fundamental harmonic). **(3 points)**

d) In light of the discussion that we had in class about power transmitted in a wave, do you think that in this system any power is being transmitted? Explain shortly. **(2 points)**

Exercise 3 - Heat capacity (12 points)

A mass $M = 100\,\mathrm{g}$ of some substance is attached to a spring (of negligible mass) inside a fixed Tungsten tube that has a mass of $M_W = 100\,\mathrm{g}$. The spring is stretched by $\Delta L = 50\,\mathrm{cm}$ from its equilibrium position and the spring constant is $k = 40\,\frac{\mathrm{N}}{\mathrm{m}}$. The mass is released and starts **oscillating** in the Tungsten tube. The characteristic damping time is $\tau = 300\,\mathrm{sec}$. The entire system is in vacuum and isolated from the environment. The initial temperature is $300\,\mathrm{K}$ and the final temperature, after the mass stopped oscillating, is $300.2\,\mathrm{K}$.
The heat capacity of Tungsten is $c_W = 0.135\,\frac{\mathrm{kJ}}{\mathrm{kg \cdot K}}$.



i) Calculate the angular frequency ω', of the oscillation. **(2 points)**

ii) Calculate the specific heat capacity of the material. **(3 points)**

iii) Assuming the process is quasi-static, plot the temperature of the material as function of time. **(2 points)**

iv) Assume the mass and the tube have equal temperature at all times. What is the change in entropy, ΔS, of the tungsten tube?
For solving, consider a corresponding reversible process. **(3 points)**

v) Now, a few grams of grease is added to the tube which increases the friction between the mass and the tube. Starting again from the same initial temperature, is the final temperature higher, lower, or the same? Justify your answer (shortly). **(2 points)**

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Exercise 4 - Brayton cycle (14 points)

A Brayton cycle has 4 steps:

1. Adiabatic compression.
2. Isobaric heat addition.
3. Adiabatic expansion.
4. Isobaric heat rejection.

An ideal gas with two degrees of freedom ($c_v = R$) is used as the working substance in a Brayton engine. The cycle starts with atmospheric pressure of P_1, Volume V_1 and temperature T_1. The pressure in step 2 is $P_2 = 4P_1$, and the highest temperature in the cycle is $8T_1$.
Express your answers for the following questions using P_1, V_1 and T_1.

i) Calculate the volume and temperature at the beginning of each step. Plot the P-V and S-T diagrams of the cycle. **(5 points)**

ii) Calculate the total (net) amount of work done by the engine in one cycle. **(5 points)**

iii) Calculate the efficiency of the engine. **(4 points)**

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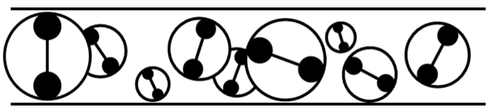
Exercise 5 - Entropy and heat capacity (10 points)

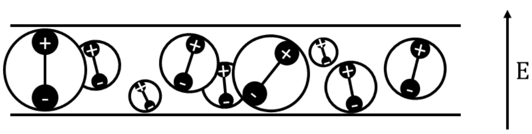
e) An atom trap can capture at most three atoms in three defined positions. Each position can be occupied by one atom at most. In one experiment only two atoms were captured.
Calculate the entropy of the system. Remember the relation between entropy and microscopic states. **(3 points)**

f) Calculate the entropy of an array of 3 atoms, where each atom has 3 different spin configurations $\{+1, 0, -1\}$ with the same energy. **(2 points)**

g) A diatomic ideal gas is placed in a 2 dimensional atom trap (the trap restricts the center of mass motion to 2 dimensions, but does not affect the atoms' ability to rotate). What is the heat capacity at constant volume, c_v, of the gas? **(3 points)**



h) Now, assume that the diatomic molecules have a finite dipole moment. An electric field, E, is applied normal to the trap. The molecules begin to be preferentially oriented in the direction of the electric filed, and with very high electric field ($E \to \infty$) all the molecules are oriented in the direction of the electric field. (The energy, ΔU, required to rotate the molecule to the opposite direction when $E \to \infty$ is very large compared to $k_B T$: $\Delta U \gg k_B T$)
What is the heat capacity when E is very large?
Qualitatively sketch the heat capacity at constant volume as function of the electric field. **(2 points)**



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Extra sheet #1

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Extra sheet #2

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Extra sheet #5