浙江大学 2023－2024 学年春夏学期

《普通物理学 I （H）》课程期末测试卷

课程号： 061R0060 ，开课学院： 物理学院

考试试卷：√A 卷、B 卷（请在选定项上打√）

考试形式：√闭、开卷（请在选定项上打√），允许带 纸质词典、计算器 入场

考试日期： 2024 年 6 月 22 日， 考试时间： 120 分钟

诚信考试，沉着应考，杜绝违纪。

考生姓名： ______________ **学号：** ______________ **所属专业：** ______________

题序	I	II	III. 13	III. 14	III.15	III. 16	III. 17	**总 分**
得分								
评卷人								

Physical constants you may use:

Gravitational acceleration on the earth's surface	$g = 9.80\ \mathrm{m/s^2}$
Speed of light in a vacuum	$c = 3.00 \times 10^8\ \mathrm{m/s}$
Boltzmann constant	$k = 1.38 \times 10^{-23}\ \mathrm{J/K}$
Molar gas constant	$R = 8.31\ \mathrm{J/(mol \cdot K)}$
Absolute zero	$0\ \mathrm{K} = -273.15\ ^\circ\mathrm{C}$

Relative atomic mass: H – 1, C – 12, N – 14, O – 16.

Enjoy your exam and good luck!

I. MULTIPLE CHOICE

[18 points] Choose only ONE correct answer.

(1) **[3 points]** On March 30th, 2024, the Experimental Advanced Superconducting Tokamak (先进实验超导托卡马克) (EAST) in Hefei, China, successfully achieved plasma operation (等离子体运行) with ion (离子) temperatures reaching 10^8 K, bringing us closer to the goal of controlled nuclear fusion (可控核聚变). Assuming the main ions in the plasma are deuterium (氘) ions following a Maxwell distribution, and with a mass $m_\mathrm{D} \approx 2m_\mathrm{p} = 3.35 \times 10^{-27}$ kg, the average speed of the ions is approximately?

(A) 10^4 m/s　　(B) 10^5 m/s　　(C) 10^6 m/s

(D) 10^7 m/s　　(E) 10^8 m/s

(2) [3 points] How many of the following four processes in isolated systems are certainly forbidden by the first law of thermodynamics?

i)	*An ice cube is placed in hot coffee; the ice gets colder and the coffee gets hotter.*
ii)	*Cold water is placed in a cold glass; the glass gets colder and the water gets colder.*
iii)	*A student builds an automobile engine (汽车发动机) that converts into work the heat released when water changes to ice.*
iv)	*Make dry ice (干冰) by allowing carbon dioxide (二氧化碳) gas to expand in a bag.*

(A) Zero　　(B) One　　(C) Two

(D) Three　　(E) Four

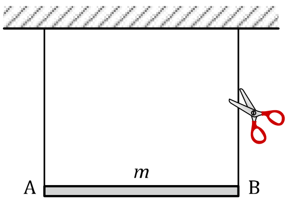
(3) [3 points] A uniform rod of mass m is suspended (悬挂) horizontally by two light strings attached to the ceiling, as shown in the figure. If one of the strings is cut off (剪断), what is the tension (张力) in the other string at the moment after this cut-off?

(Hint: Consider point A as the instantaneous pivot (瞬时转轴).)

(A) mg　　(B) $\frac{mg}{2}$

(C) $\frac{mg}{3}$　　(D) $\frac{mg}{4}$

(E) $\frac{3mg}{4}$



(4) [3 points] Ocean waves can often be observed in nature. If the ocean is enough deep, the angular frequency ω and the wavelength λ of the ocean waves satisfy the relationship: $\omega^2\lambda = 2\pi g$, where g is the gravitational acceleration. What is the correct ratio between the phase speed u_{ph} and the group speed u_{g} for this type of wave?

(A) $u_{\mathrm{ph}}/u_{\mathrm{g}} = 2$

(B) $u_{\mathrm{ph}}/u_{\mathrm{g}} = \sqrt{2}$

(C) $u_{\mathrm{ph}}/u_{\mathrm{g}} = 1$

(D) $u_{\mathrm{ph}}/u_{\mathrm{g}} = 1/\sqrt{2}$

(E) $u_{\mathrm{ph}}/u_{\mathrm{g}} = 1/2$

(5) [3 points] The two Carnot cycles by the same type and amount of ideal gas are shown in the figure: Cycle 1 ($A_1 \to B_1 \to C_1 \to D_1 \to A_1$) and Cycle 2 ($A_2 \to B_2 \to C_2 \to D_2 \to A_2$). If the efficiencies of the two cycles are denoted as η_1 and η_2, and the heat (absolute value) released to the low-temperature heat source in the two cycles are denoted as Q_1' and Q_2', respectively. Which of the following comparisons is correct?

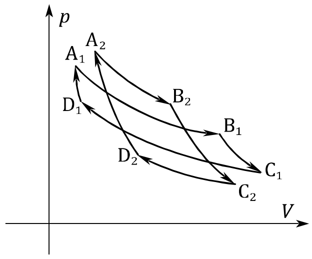
(A) $\eta_1 = \eta_2$ and $Q_1' = Q_2'$

(B) $\eta_1 > \eta_2$ and $Q_1' > Q_2'$

(C) $\eta_1 > \eta_2$ and $Q_1' < Q_2'$

(D) $\eta_1 < \eta_2$ and $Q_1' < Q_2'$

(E) $\eta_1 < \eta_2$ and $Q_1' > Q_2'$

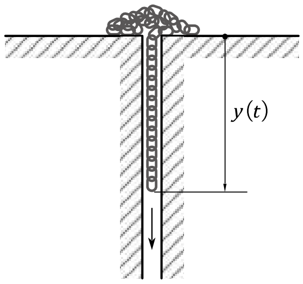


(6) **[3 points]** There is a small hole in the middle of a table. A long, thin, uniform necklace (项链) is placed naturally coiled (盘绕) around the hole. If you slightly put one end of the necklace into the hole and then release it, this end will fall through the hole. Assuming the part of the necklace not yet (尚未) in the hole remains still, and ignoring all friction, what is the equation for the fallen distance $y(t)$ by the lowest end of the necklace? Let $t = 0$ be the moment when the necklace starts to fall. (Hint: If you find it difficult to calculate the integral (积分), try to verify each answer after getting the equation.)

(A) $y(t) = \frac{1}{2}gt^2$ (B) $y(t) = \frac{1}{3}gt^2$

(C) $y(t) = \frac{1}{4}gt^2$ (D) $y(t) = \frac{1}{6}gt^2$

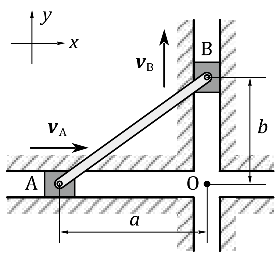
(E) $y(t) = \frac{1}{8}gt^2$



II. BLANK FILLING

[26 points] Fill in your answers in the blanks.

(7) **[5 points]** On the cross track, small slider (滑块) A and B can only slide along the x-direction and y-direction tracks, respectively. They are connected by a fixed-length rod. If slider A moves to the right at a constant velocity $\boldsymbol{v}_\mathrm{A}$, when the distances of slider A and slider B to the intersection point (交叉点) O are a and b respectively, the magnitudes of the velocity and acceleration of slider B are $v_\mathrm{B} =$ ____________ and $a_\mathrm{B} =$ ____________.

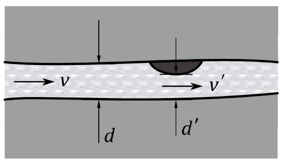


(8) **[5 points]** A small artery (动脉) with a diameter of $d = 5.00$ mm is blocked by a hard plaque (斑块). The effective diameter of the narrow (狭窄) part is $d' = 3.00$ mm, and the average blood flow speed in the narrow part is $v' = 50.0$ cm/s. At 37 °C, the viscosity of the blood is $\eta = 3.00$ mPa · s and the density is $\rho = 1.05$ g/cm^3.

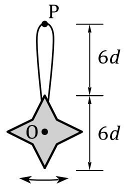
(a) The average blood flow speed in the unchanged part is $v =$ ____________.

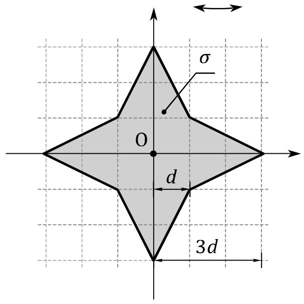
(b) Will turbulence occur? ____________.

(Fill in "Yes" or "No". The critical Reynolds number is $R \sim 2000$.)



(9) **[5 points]** A <u>"primogem" pendant</u> (“原石”挂坠) can be seen as a uniform plate with a surface density of σ, shaped like a <u>center-symmetric four-pointed star</u> (中心对称的四芒星). Its sizes are shown in the right figure, where each small square <u>grid</u> (网格) has a side length of d.





(a) The pendant's rotational inertia about its center point O is $I_O =$ ____________.

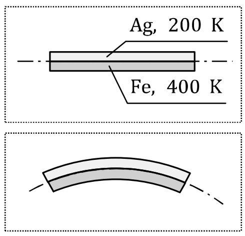
(b) If suspend it by a light string at point P as shown in the figure, with the end part of the string fixed to the pendant, and allow it to swing at a small angle in the <u>vertical plane</u> (竖直平面) around point P, the pendant can be considered as a physical pendulum. The oscillation period of the pendant is $T =$ ____________.

(All the <u>axes of rotation</u> (转轴) <u>are perpendicular to</u> (垂直于) the plane of the pendant.)

(10) **[3 points]** There is an <u>transmitter</u> (发射器) fixed on the seabed, <u>emitting</u> (发射) a beam of <u>ultrasound</u> (超声波) with a frequency of $f = 30000$ Hz. The wave is <u>reflected</u> (反射) back by an <u>approaching submarine</u> (正在接近的潜艇). The reflected wave and the initial wave combine to form a "beat" frequency of $f_{\text{beat}} = 241$ Hz. Then the approaching speed of the submarine is $v =$ ____________. The speed of ultrasound in seawater is known to be $c_s = 1500$ m/s. (Hint: Reflection does not change the frequency of the wave.)

(11) **[3 points]** A <u>silver wire</u> (银丝) with temperature 200 K and an <u>iron wire</u> (铁丝) with temperature 400 K, both with the same cross-sectional area, initially straight and of equal length. They are connected together at their both ends. When they reach a state of thermal equilibrium, they are bent into a <u>circular arc</u> (圆弧). Then the temperature at thermal equilibrium is $T =$ ____________.

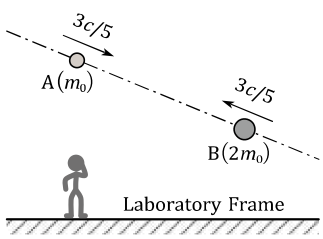
(The initial densities of silver and iron are $\rho_{\text{Ag}} = 10.49\ \text{g/cm}^3$ and $\rho_{\text{Fe}} = 7.87\ \text{g/cm}^3$, and the specific heats are $c_{\text{Ag}} = 233\ \text{J/(kg}\cdot\text{K)}$ and $c_{\text{Fe}} = 449\ \text{J/(kg}\cdot\text{K)}$. The process involves no heat exchange with the surroundings. If you also know the thermal expansion coefficients of silver and iron, you can further calculate the radius of the arc!)



(12) **[5 points]** Particle A with rest mass m_0 and particle B with rest mass $2m_0$ move towards each other along the same line. In the laboratory frame, their speeds are both measured to be $3c/5$.

(a) Their relative speed is $v' =$ ____________.

(b) If they collide and <u>merge into</u> (合并为) a new particle with no energy loss during the collision, the rest mass of this new particle is $M_0 =$ ____________.



III. CALCULATION AND ANALYSIS

[56 points] Present the necessary equations and descriptions in your solution.

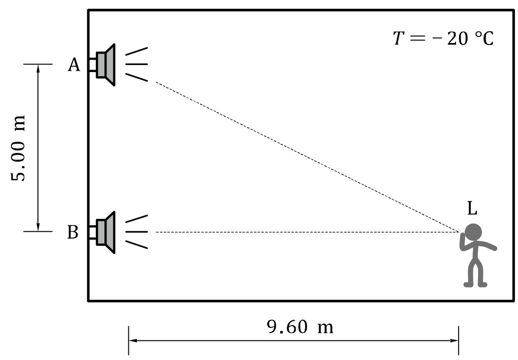
(13) [10 points] In a room with a temperature of $T = -20\ ^\circ\mathrm{C}$, a cold environment sound test (寒冷环境音响测试) is conducted. The positions of two speakers (扬声器), A and B, and the listener, L, are as shown in the figure. Driven by the same input signal (输入信号), the two speakers emit sound waves with the same frequency, the same intensity, and the same phase. Ignore any attenuation (衰减) and reflection of the sound waves.

The listener notices that he seems to be in a position where the sound is the loudest — no matter which direction he takes a few steps, the sound he hears becomes weaker.

(a) Calculate the speed of sound c_s in the air in this room.

(b) Find the possible lowest frequency f_1 and the second lowest frequency f_2 of the sound.

(Hint: The speed of sound in air is given by $c_s = \sqrt{\gamma RT/M}$, where γ is the specific heat ratio of air, M is the molar mass of air, T is the temperature of air, and R is the molar gas constant. The main components of air are 4/5 nitrogen (N_2) and 1/5 oxygen (O_2). The range of frequencies audible (可听) to the human ear is $20 \sim 20000$ Hz.)



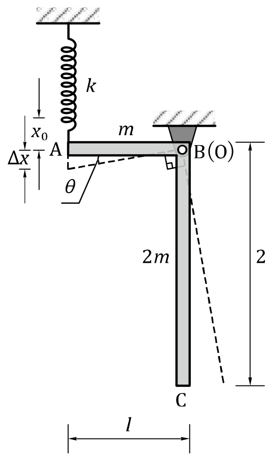
(14) **[10 points]** A uniform L-shaped ruler (L 形尺) consists of two sections: section $\overline{AB}$ with a length of l and mass m, and section $\overline{BC}$ with a length of $2l$ and mass $2m$. The angle between the two sections is a right angle (直角). The ruler is suspended at point B on a smooth pivot O, allowing it to rotate, and a vertical light spring with a stiffness coefficient (劲度系数) k is used to lift point A. When in equilibrium, section $\overline{AB}$ is perfectly horizontal, and section $\overline{BC}$ is perfectly vertical. Ignore all resistance.

(a) Find the elongation (伸长量) x_0 of the spring at equilibrium.

(b) If the L-shaped ruler swings around pivot O with a small angle, prove that it is a simple harmonic oscillation.

(c) Find the period T of this simple harmonic oscillation.

(Hint: If the angle θ is small, you can think $\sin\theta \approx \theta$, $\cos\theta \approx 1$, and the spring's additional elongation $\Delta x \approx l\theta$.)

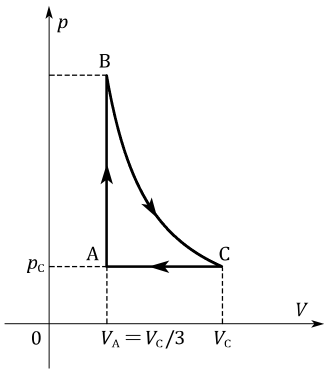


(15) **[12 points]** In a heat engine, 1.44 kg of <u>methane</u> (甲烷) (CH_4), considered as an ideal gas, goes through a cycle: $\mathrm{A} \rightarrow \mathrm{B} \rightarrow \mathrm{C} \rightarrow \mathrm{A}$. From A to B, the volume remains constant. From B to C, the process is adiabatic. From C to A, the pressure remains constant and the volume being compressed to <u>one-third</u> (三分之一).

(a) What is the efficiency η of this heat engine?

(b) Find the entropy change ΔS for each of the three processes.

(c) If the pressure of the gas at state C is $p_\mathrm{C} = 215$ kPa, and its volume at state C is $V_\mathrm{C} = 996$ L, calculate the temperature T_B of the gas at state B.



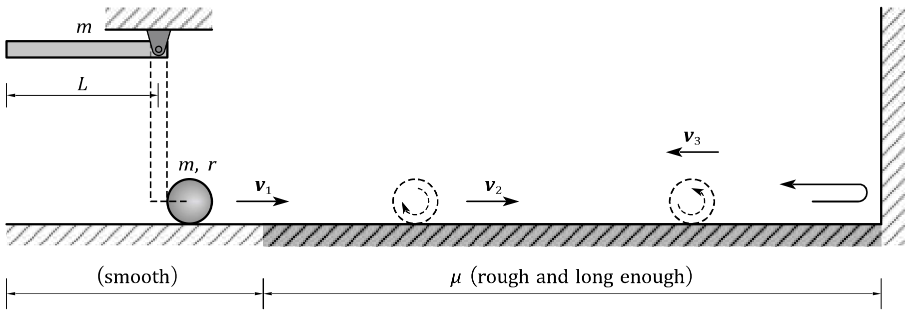
(16) **[12 points]** As shown in the figure, a uniform thin rod with mass m and length L is suspended from a smooth pin (销钉) at its top end. The rod is released from rest in a horizontal position. When it swings down to the vertical position, its bottom end hits a ball (a solid sphere with mass also m and radius r) which is initially at rest on a smooth horizontal track. The collision is completely elastic (完全弹性的), and the point of hit (撞击点) is at the same height as the center of the ball. After the hit, the ball starts to slide without rolling.

(a) Find the velocity $\boldsymbol{v}_1$ of the ball after the hit.

(b) After sliding for a certain distance, the ball enters a rough horizontal track with a friction coefficient of μ. The track is long enough for the ball to eventually (最终) reach a state of rolling without slipping. Find the velocity $\boldsymbol{v}_2$ of the ball in this state.

(c) After that, the ball hits a vertical wall, and the collision is also completely elastic. Find the velocity $\boldsymbol{v}_3$ of the ball when it again reaches rolling without slipping on the enough long rough track.

(All velocities refer to (指) the velocity of the ball's mass center.)

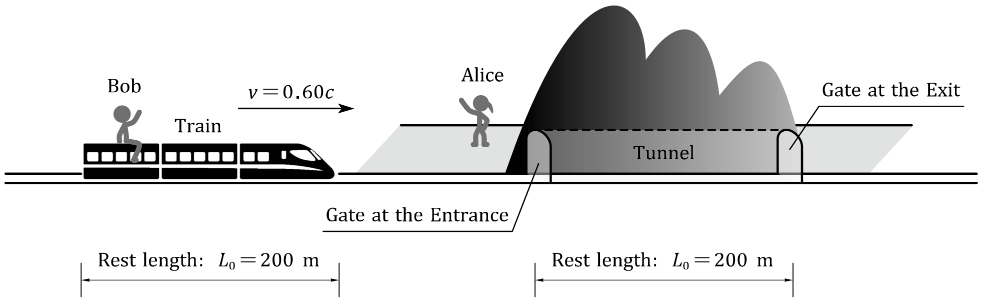


(17) **[12 points]** A story about the <u>"train and tunnel paradox"</u> (火车隧道佯谬):

A train with a rest length of $L_0 = 200\ \text{m}$ is traveling on a rail at a constant speed of $v = 0.60c$. It will pass through a tunnel that also has a rest length of $L_0 = 200$ m. Alice is an observer standing on the ground, and Bob is an observer standing in the train.

Alice:	*"The train has become shorter than the tunnel."*
Bob:	*"The tunnel has become shorter than the train."*
Alice:	*"If the two gates located at the tunnel's <u>entrance</u> (入口) and <u>exit</u> (出口) are closed <u>simultaneously</u> (同时地) at the right moment, the train can be <u>completely enclosed within</u> (完全封闭于…内) the tunnel."*
Bob:	*"That's impossible!"*

Who is correct?



(a) Find the length of the train as seen by Alice and the length of the tunnel as seen by Bob.

(b) If Alice chooses the moment when she sees the <u>midpoint</u> (中点) of the train <u>coincide with</u> (重合于) the midpoint of the tunnel to simultaneously close the two gates at the entrance and exit of the tunnel, does Bob see these two gates close simultaneously? If not, which gate closes first? Find the time difference $\Delta t'$.

(c) So, can Alice completely enclose the train within the tunnel by doing this? Describe the whole process seen by Bob. Do they see the same <u>outcome</u> (结局)?

(Assume that once any part of the train hits a gate, it stops immediately; while the rest part of the train continues to move forward.)

(d) In the previous question, we did not treat the train as a <u>rigid body</u> (刚体). If we consider a rigid body model in special relativity, what <u>contradictions</u> (矛盾) might come up? Try to give an example to explain. **(Bonus)**