浙江大学 2020–2021 年春夏学期

《普通物理学 I （H）》课程期中测试卷

课程号：<u>061R0060</u>，开课学院：<u>物理学系</u>

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<u>纸质词典、计算器</u>入场

考试日期：<u>2021</u>年<u>5</u>月<u>15</u>日，考试时间：<u>120</u>分钟

诚信考试，沉着应考，杜绝违纪。

考生姓名：_______________ **学号：**_______________ **所属院系：**_______________

题序	I	II	III. 13	III. 14	III.15	III. 16	III. 17	III. 18	总 分
得分									
评卷人									

Physical constants you may use:

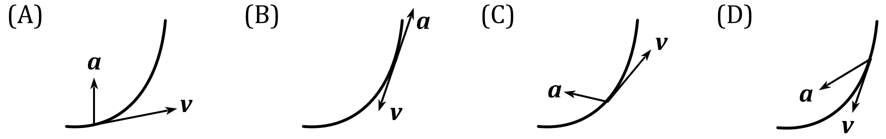
Gravitational acceleration on the earth's surface	$g = 9.80\ \mathrm{m/s^2}$
Speed of light in a vacuum	$c = 3.00 \times 10^{8}\ \mathrm{m/s}$
Gravitational constant	$G = 6.67 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}$
Reduced Planck constant	$\hbar = 1.05 \times 10^{-34}\ \mathrm{J \cdot s}$

Enjoy your exam and good luck!

I. MULTIPLE CHOICE

[24 points] Choose only ONE correct answer.

(1) **[3 points]** A particle decelerates along a curve. Which of the following figures can correctly show the directions of its velocity and acceleration?



(2) **[3 points]** A train travels along a straight track from south to north in Hangzhou (30° N，120° E). Which side of the track will be more squeezed because of Coriolis force?

(A) East side;

(B) West side;

(C) Both sides;

(D) No effect.

(3) **[3 points]** An object is moving in a circle at the constant speed v. Which of the following descriptions about the magnitude of the time derivative (时间导数) of its momentum is correct?

(A) It is zero;

(B) It is proportional to v;

(C) It is proportional to v^2;

(D) It is proportional to v^3.

(4) **[3 points]** In order to explain why the rat that fell from the ceiling is safe , let's calculate the dynamic pressure (动压) on its bones when it falls to the ground. Given that the dynamic pressure $\sigma = \frac{1}{2}\rho v_{\max}^2$, ρ is the density of the organism (Assuming it is the same for all animals), $v_{\max}$ is the terminal speed (收尾速度) of falling. If a rat and a man fall from the same height, and the body size of the man is 20 times the size of the rat, how many times the dynamic pressure on the bones of the rat when it falls to the ground than on the bones of the man?

(Assuming air resistance $f \propto Sv$, S is the cross-section (横截面积) when falling. The initial position is high enough that both the rat and the man can reach terminal speeds.)

(A) 1 ;

(B) 1/20 ;

(C) 1/400 ;

(D) 1/8000 .

(5) **[3 points]** A force $\boldsymbol{F}$ that changes according to $F = 7t^2 + 3t$ (SI) pushes a particle to move along a straight line in the water. The motion equation of the particle is $x = 2t^3$ (SI). The moving direction is the same as the direction of $\boldsymbol{F}$. From $t = 0$ s to $t = 2$ s, how much work is done by $\boldsymbol{F}$ approximately?

(Choose the closest one.)

(A) 72 J ;

(B) 340 J ;

(C) 544 J ;

(D) 816 J .

(6) **[3 points]** Consider three uniform objects: a solid sphere, a solid disk, and a metal ring. All of them have the same mass m and radius r. All are placed at the same point on the same inclined plane where they will roll without slipping to the bottom. Which object will reach the bottom of the incline in the shortest time?

(A) The solid sphere;

(B) The solid disk;

(C) The metal ring;

(D) All reach at the same time.

(7) **[3 points]** Astronomers believe that there may be a giant black-hole in the center of the Milky Way. They discovered that stars about 6 billion kilometers away from the center of the Milky Way are rotating around the center at a speed of $2000\ \mathrm{km/s}$. Using classical mechanics to estimate: If this black-hole really exists, what is its possible maximum radius (also called the Schwarzschild radius (史瓦西半径))?

(Hint: *A black-hole is a celestial body with great mass and strong gravitation. All objects within the radius of the black-hole, even light, cannot escape, so the magnitude of the escape velocity (逃逸速度) on a black-hole's surface is c .*)

(A) $5\times10^{6}\ \mathrm{m}$;

(B) $5\times10^{8}\ \mathrm{m}$;

(C) $5\times10^{10}\ \mathrm{m}$;

(D) $5\times10^{12}\ \mathrm{m}$.

(8) **[3 points]** In 1899, Max Planck devised a complete system of so-called "natural" units that was based on the three fundamental physical constants: reduced Planck constant (约化普朗克常量) $\hbar$, gravitational constant G, and light speed c. If we change the usual SI units (which uses "1 meter", "1 second", and "1 kilogram" as the bases for length, time, and mass) to this new unit system (which will use new bases l_{P}, t_{P}, and m_{P}, respectively), these three physical constants will all become 1, which can make equations simpler. In Planck's new unit system, what are the bases of length, time, and mass?

(Hint: *You can look up these physicial constants at the beginning of the exam paper.*)

(A) $l_{\mathrm{P}}=\sqrt{\dfrac{\hbar G}{c}}$, $t_{\mathrm{P}}=\sqrt{\dfrac{\hbar G}{c^3}}$, $m_{\mathrm{P}}=\sqrt{\dfrac{\hbar c}{G}}$;

(B) $l_{\mathrm{P}}=\sqrt{\dfrac{\hbar G}{c}}$, $t_{\mathrm{P}}=\sqrt{\dfrac{\hbar G}{c^3}}$, $m_{\mathrm{P}}=\sqrt{\dfrac{\hbar G}{c^5}}$;

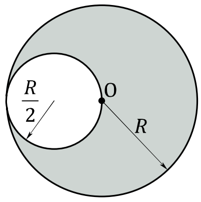
(C) $l_{\mathrm{P}}=\sqrt{\dfrac{\hbar G}{c^3}}$, $t_{\mathrm{P}}=\sqrt{\dfrac{\hbar G}{c^5}}$, $m_{\mathrm{P}}=\sqrt{\dfrac{\hbar G}{c}}$;

(D) $l_{\mathrm{P}}=\sqrt{\dfrac{\hbar G}{c^3}}$, $t_{\mathrm{P}}=\sqrt{\dfrac{\hbar G}{c^5}}$, $m_{\mathrm{P}}=\sqrt{\dfrac{\hbar c}{G}}$.

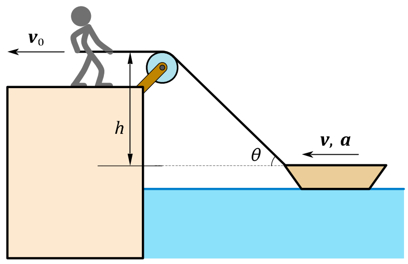
II. BLANK FILLING

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

(9) **[4 points]** As shown in the right figure, a uniform disk with an original mass of M and a radius of R is dug out a small circle with a radius of $R/2$ that is inscribed to the big circle. The distance between the center of mass of the remaining part and point O is $r_C =$ ________, and the rotational inertia of the remaining part about point O is $I_O =$ ________.

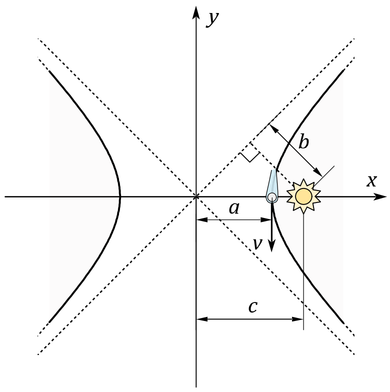


(10) **[4 points]** As shown in the right figure, a man uses a light rope to pull the boat to the shore through a fixed pulley. The distance of the pulley above the water surface is h. If he pulls the rope at a constant velocity $\boldsymbol{v}_0$, at the moment when the angle between the rope and the horizontal direction is θ, the speed of the boat is $v =$ ________, and the magnitude of the acceleration of the boat is $a =$ ________. (Ignore all resistance.)



(11) **[4 points]** Assuming that the orbit of a comet (彗星) in the solar system is a branch of a hyperbola (双曲线). Its orbit equation is $\dfrac{x^2}{a^2} - \dfrac{y^2}{b^2} = 1$, and the sun is located at one of the focal points (焦点) of the hyperbola. Then the radius of curvature (曲率半径) of the comet's orbit at the vertex (顶点) of the hyperbola is $\rho =$ ________.

(Hint: *Imagine that the comet approaches the sun from infinity at an initial velocity* v_0*, and is only affected by the sun's gravitation field, which satisfies the conservation of energy and the conservation of angular momentum.*)



(12) **[4 points]** The reactor (反应堆) in a nuclear power plant requires low-speed "thermal neutrons" (热中子) to maintain the slow fission (裂变) reaction, i.e. chain reaction (链式反应), but the reaction releases high-speed "fast neutrons" (快中子). In the reactor, we make "fast neutrons" constantly collide with the carbon atoms (${}^{12}_{6}C$) in the graphite rod (石墨棒), so that it can gradually slow down and eventually become the "thermal neutrons" we need. Assuming that the average kinetic energy of a "fast neutron" is 2.0×10^{6} eV and the average kinetic energy of a "thermal neutron" is 0.025 eV, the carbon atoms are stationary before each collision. All collisions are elastic. How many collisions does a "fast neutron" go through to become a "thermal neutron"? __________.

(Hint: *Obviously we know that the mass of a carbon atom is about* 12 *times the mass of a neutron.* "eV" *is the symbol of electron volt* (电子伏特) *, a unit of energy.*)

III. CALCULATION AND ANALYSIS

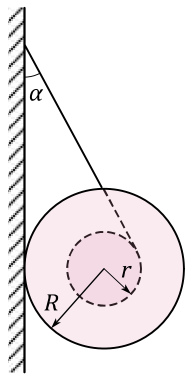
[60 points] Present the necessary equations and descriptions in your solution, and correctly handle the unit and number of significant digits of your answers (if necessary).

(13) **[8 points]**

As shown in the following figure, the end of a drawn yarn (纱线) from a uniform yarn ball (纱球) is fixed at the wall so that the yarn ball is hung against the wall. The mass of the yarn ball is $m=2.0$ kg, its radius is $R=10$ cm, the distance between the drawn yarn and the center of the ball is $r=0.50$ cm, and the the coefficient of static friction between the wall and the ball is $\mu=0.10$.

(a) When the yarn ball is in a critical (临界的) equilibrium state, what is the angle α between the drawn yarn and the wall?

(b) In this case, find the tension in the drawn yarn.

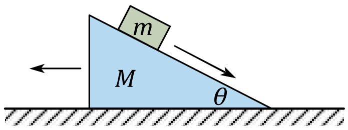


(14) [8 points]

A spacecraft flies in space at a constant velocity $\boldsymbol{v}$. During the flight, it encountered an oncoming dust stream (迎面而来的尘埃流) with a velocity of $\boldsymbol{u}$, and the dust particles were deposited on the surface of the spacecraft at a rate of $\frac{\mathrm{d}M}{\mathrm{d}t}$. (This is because we record the total mass of the spacecraft as M.) How much driving force is required to remain the spacecraft's constant velocity? All velocities are relative to distant galaxies.

(15) [8 points]

As shown in the following figure, a prism (棱镜) with a mass of M can slide on a horizontal plane, and a block with a mass of m is placed on the prism. The inclination angle of the prism is θ. All the surfaces are frictionless. How much force is on the surface of the prism by the block as the block slides down?



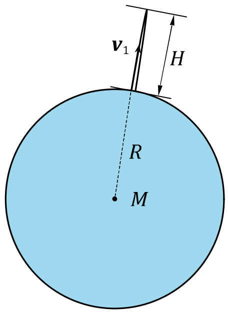
(16) [12 points]

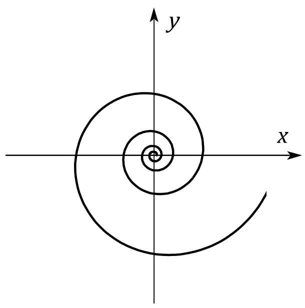
Launch a rocket vertically upwards from the surface of the earth at the first cosmic velocity $\boldsymbol{v}_1$. Suppose the mass of the earth is $M = 5.98 \times 10^{24}$ kg and the radius of the earth is $R = 6370$ km. Do not consider any rotation of the earth and air resistance.

(a) Calculate the maximum height H that the rocket can reach.

(b) Find the total time for the rocket from launch to landing.

(Hint: *You can use calculus,* $\int\sqrt{\dfrac{r}{a-r}}\,\mathrm{d}r = a\cdot\arctan\sqrt{\dfrac{r}{a-r}}-\sqrt{r(a-r)}+C$ *is given. You can also approximate the rocket's orbit as* *<u>a very narrow ellipse (椭圆)</u>, and the area of an ellipse is* $S=\pi ab$. *<u>You only need to choose ONE method.</u>*)





(17) [12 points]

A particle moves in a plane according to:

$$x(t)=R\,\mathrm{e}^{kt}\cdot\cos(\omega t)$$
$$y(t)=R\,\mathrm{e}^{kt}\cdot\sin(\omega t)$$

(a) Derive the velocity and the acceleration of the particle over time, i.e. the functions $\boldsymbol{v}(t)$ and $\boldsymbol{a}(t)$.

(b) Derive the magnitude of tangential acceleration and centripetal acceleration of the particle over time, i.e. the functions $a_\tau(t)$ and $a_\mathrm{n}(t)$.

(c) Define $b=k/\omega$, find the equation of the curve in which the particle moves in the polar coordinate system (r,θ). This curve is called "logarithmic spiral" (对数螺线).

(d) Calculate the arc length of the logarithmic spiral from $\theta=0$ to $\theta=2\pi$.

(e) Logarithmic spirals are found in many natural phenomena, such as in Nautilus (鹦鹉螺), cyclones (气旋), and spiral arms of spiral galaxies (旋涡星系的旋臂). Why do these natural phenomena have a logarithmic spiral form? Try to explain the reason with your conjecture.

▲ Nautilus

▲ Cyclone

▲ Arms of spiral galaxies

(18) [12 points]

A football (seen as a uniform hollow spherical shell) with a mass of m and a radius of r rolls without slipping on the ground. The velocity of the center of the football is $\boldsymbol{v}_0$.

Suddenly, it hits a wall.

Do not consider any air resistance and rolling resistance (滚动摩阻).

(a) Assuming that the wall is smooth, the collision between the football and the wall is completely elastic. The coefficient of kinetic friction between the ground and the football is μ. How will this football move next? Please analyze all the processes and find the magnitude of the center velocity and angular velocity when the football can roll without slipping again.

(b) If it is a completely inelastic hollow ball, the wall is rough (with the same coefficient of kinetic friction of μ). How will this ball move next? Will it roll up? How high can it roll? (Assume that the ball after the collision does not touch the wall. It is not required to analyze the process of the ball after it hits the ground.)

(c) In fact, the collision between the football and the wall is not completely elastic or inelastic, which is always between the above two situations. How will the center of this football move after the collision? Try to give a qualitative (定性的) conclusion.

(d) As shown in the following figure, pick up the football in (a), place it on one highest point of a semicircular (半圆形) smooth track with a radius of R in a vertical plane and release it from the stillness, so that it rolls down without slipping. Calculate the magnitude of center velocity v_C, angular velocity ω and force on the track F_N when it rolls to the lowest point of the track.