Physics 1B-1 Winter 2021
Exam 2

February 25th

Due to the extraordinary circumstances caused by the COVID-19 pandemic, the Exam is online opened-textbook opened-notes exam.

You are allowed to use the textbook (and/or text e-book), your notes, your home assignments and home assignment solutions and calculators; please do not consult any other materials. This exam is an attempt to evaluate the individual proficiency of the students in the subject of this class. Group work of students on the problems is strictly prohibited. Please respect this guidance to avoid conflict with the UCLA registrar regulations.

Exam proctoring will be administered during the originally scheduled for lecture time period from 14:00 to 15:50 (Pacific) using Zoom (help can be found at https://ucla.zoom.us). Any questions and requests for clarification about the problems in the exam must be asked via Zoom private chat window to proctor to avoid disruption of the work of other students taking exam. If needed, the answers to the questions and requests will be provided to the whole class via Zoom.

Please use blank paper (or blank graph paper) to write your solutions. You can also use iPads, but in all cases, you are responsible to generate PDF file for the submission of your work for grading. Write your name, ID and problem number on each page to minimize possible misunderstanding.

The PDF files of your work must be uploaded to the Gradescope site no later than 15 minutes after the official end of the exam shown above. Only PDF format is allowed to be uploaded.

Problems are not ordered in the order of complexity. Please look at all problems and start with those, which seem the most familiar to you. It is not expected that the majority of the class will complete all problems (including **Extra Credit** questions) in a given time. The hints are provided in each problem to help you to save time.

Problem	Points	Extra Credit
Problem 1	_______10	NA
Problem 2	_______20	NA
Problem 3	_______30	_____30
Problem 4	_______15	_____15
Problem 5	_______40	_____40

Name	ID	Total	Extra Credit	Percentage
		_______115	_______85	

1. In one of the original Doppler experiments, a tuba was played on a moving flat train car at a frequency of $f = 75$ Hz, and a second identically calibrated tuba played the same tone while at rest in the railway station. The train was moving with a top speed of $\upsilon = 16\ \frac{\mathrm{m}}{\mathrm{s}}$. Assume that the speed of sound is $c_s = 344\frac{\mathrm{m}}{\mathrm{s}}$ at $T = 20°\mathrm{C}$ (293°K) and answer the following questions.

    (a) What beat frequency Δf_s was heard in the station when train was moving toward the station? (5 points)

    (b) What beat frequency Δf_t was heard on the train ?If you have frequency measuring device, how accurate should it be to detect the difference between the two measurements? (5 points)

2. On 15 February 2013 the meteor entered the Earth's atmosphere and produced a powerful shock wave, which was detected on the ground at multiple locations allowing to determine the shock wave angle of 0.9 deg with respect to the direction of the meteor motion. The meteor, which exploded in the air 23 km above the ground with the light flash brighter than the Sun and visible up to 100 km away was estimated to have energy of 1.5×10^{15} J.

   (a) The atmospheric temperature at the altitude in the range of $12 - 30$ km is $-50°$C. Find the speed of sound at this altitude. (5 points)

   (b) Determine the velocity of the meteor. (5 points)

   (c) Estimate the mass of this meteor. (5 points)

   (d) The shock sound wave from the explosion arrived to the nearby city 3 minutes after the flash light and has blown glass in many windows. Estimate how much greater was the sound level (in dB) of the explosion for an observer standing at a point directly below the explosion? (5 points)

   The Chelyabinsk meteor, described in this problem, is the largest known natural object to have entered Earth's atmosphere since the 1908 Tunguska event, which released 10 to 100 times more energy. The explosion power of the Chelyabinsk meteor was ~ 30 times larger in energy than the atomic bomb detonated in Hiroshima.

3. A neutron consists of three charged elementary particles, called quarks: one u quark, with charge $+\frac{2}{3}e$, and two d quarks, each with charge $-\frac{1}{3}e$ ($e = 1.6 \times 10^{-19}C$). Assume that u quark is placed at the origin and two d quarks are placed at the positions $+r_n\vec{e}_z$ and $-\ r_n\vec{e}_z$, where r_n is the radius of the neutron and $\vec{e}_z$ is the unit vector along $z-$axis.

   (a) The characteristic electrostatic energy of interaction of quarks in neutron or proton is $U = \frac{1}{4\pi\epsilon_0}\frac{e^2}{a}$, in which $a = 10^{-15}$m is the approximate size of a nucleon (neutron or proton). Estimate the U value in MeV$= 10^6$eV. (5 points)

   (b) Find neutron charge Q and its dipole moment $\vec{P}$. (5 points)

   (c) Derive formula for the energy of electrostatic interaction of quarks in neutron $U_n(l)$ as a function of distance l between u and d quarks. (5 points) *Suggestion: Use notation U in this problem to simplify your writing. For example, the electrostatic energy of interaction between charge e and charge $-2e$ separated by a distance l is $U \cdot (1) \cdot (-2)\frac{a}{l} = -2U\frac{a}{l}$.*

   (d) The strong interaction force between the quarks can be both attractive and repulsive depending on the strong interaction states of the quarks (called colors) in the nucleon. In addition, the angular momentum of moving d quarks with respect to u quark can contribute to the effective repulsion potential energy at distances l smaller than r_n. Assume that the combined effective potential energy of a neutron can be modeled as $U_{\text{eff}}(l) = \frac{\beta_n}{l^2} + U_n(l)$, where $\beta_n > 0$ is constant. Find β_n given that $U_{\text{eff}}(l = r_n)$ is minimal and derive the formula for the binding energy of the neutron $U_{\text{eff}}(r_n)$. (15 points)

   (e) **[Extra Credit]** Find electric potential of the quarks in the neutron at distances much larger than the neutron radius, $r = \sqrt{x^2 + y^2 + r^2} \gg r_n$. (30 points) *Hint: Calculate Taylor expansion of the electric potential of three quarks with respect to r_n at $r_n = 0$ to the quadratic in r_n term.*

4. Consider a cube of side length a with a point charge Q placed at the center of the cube.

   (a) Apply Gauss's law and find electric field flux $\Phi = \oint \vec{E} \cdot d\vec{A}$ through the surface of the cube (5 points)

   (b) Find electric field flux $\Phi = \int \vec{E} \cdot d\vec{A}$ through one of the faces of the cube. (10 points)

   (c) [**Extra Credit**] A charge Q is placed inside a square pyramid. The length of each side of the square base is a and the charge is placed at the distance $\frac{a}{2}$ above the center of the base. Find electric field flux through one of the triangular faces of the pyramid, if the height of the pyramid h is larger than $\frac{a}{2}$. (10 points)

   (d) [**Extra Credit**] What is the electric field flux through one of the triangular faces of the pyramid, if the height of the pyramid h is less than $\frac{a}{2}$. (5 points)

5. A positive electric charge Q is distributed uniformly throughout a non-conducting sphere of radius R.

   (a) Determine potential $V(r)$ inside and outside the sphere assuming that the potential at the center of the sphere is zero, $V(0) = 0$. (20 points) *Hint: Please note that the potential is not chosen to be zero at the infinity.*

   (b) A thin passage is made along the diameter of the sphere to allow a negative charge $-q$ with mass m to move under the influence of the electric force due to the potential inside the sphere. If the charge $-q$ is released from the surface of the sphere with zero velocity, what time will it take for the charge to reach the opposite point on the surface of the sphere? (15 points) *Hint: Apply energy conservation law or Newton's second law of motion.*

   (c) Curiously, this very same problem can be formulated for the gravitational force of the Earth owing to the similar $\propto \frac{1}{r^2}$ dependences of electrostatic and gravitational forces and assuming that the mass density of our planet is uniform. In this case $\frac{1}{4\pi\epsilon_0}\frac{q}{m}\frac{Q}{R^3} \to G\frac{m}{m}\frac{M_\oplus}{R_\oplus^3} = G\frac{M_\oplus}{R_\oplus^3}$. Estimate how much time it takes for a vehicle with an arbitrary mass m (!) to travel through the center of the Earth to the other side on the surface without supplying any energy (!), should such a project was practically realized. The relevant for your calculations parameters are $G = 6.67 \times 10^{-11}\text{m}^3\ \text{kg}^{-1}\ \text{s}^{-2}$, $M_\oplus = 6 \times 10^{24}\text{kg}$, $R_\oplus = 6.38 \times 10^6\text{m}$. (5 points)

   (d) [**Extra Credit**] Imagine that the charge is released from the surface of the sphere with zero radial velocity but with a non-zero angular momentum $L = mRv_0$, where v_0 is tangential initial velocity. It will move inside the sphere under the influence of the central force of the potential. Ignore the fact that the charge needs a passage made along its trajectory, which is no longer going through the sphere center; the passage can be made later, once the trajectory is computed. If $L \neq 0$, the charge will reach a minimal distance to the center of the sphere and then will return to the surface of the sphere at some point. Calculate travel time of the charge from one point on the surface of the sphere to another point as described. (40 points) *Hint: Use energy and angular momentum conservation laws and look at the end of Lecture 4 notes related to the mathematical pendulum and how we have derived formula for its period. This problem may take time, and if you don't have enough, solve this "historical" problem at home, should you continue to be curious.*