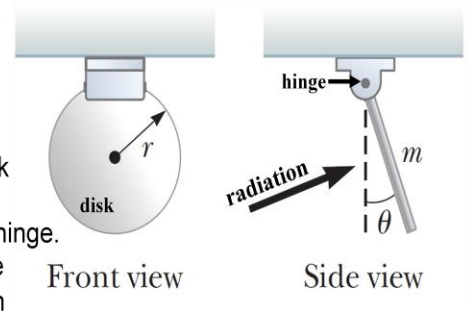
Final Examination Fall 2022   Total Possible Score: 160

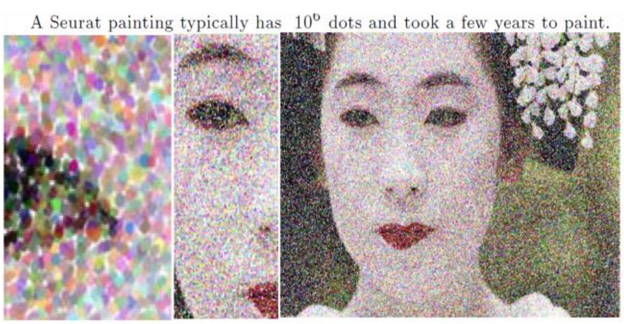
Good Luck !!!

Name: ____________   *Class:* ________   *Student number:* ____________



1. (*15 points*) A uniform circular disk of mass $m = 24.0\ g$ and radius $r = 40.0\ cm$ hangs vertically from a fixed frictionless horizontal hinge (合页) at a point on its circumference (圆周) as shown in the pictures to the right. A beam of electromagnetic radiation with an intensity of $10.0\ MW/m^2$ strikes the disk *uniformly* in a direction perpendicular to the disk's surface. The disk is perfectly absorbing, and the radiation causes the disk to rotate about the hinge. Assuming the radiation always remains perpendicular to the disk's surface as the disk rotates, what will the angle θ, as shown in the picture, be when the disk reaches its new equilibrium position? ($g = 9.8\ m/s^2$)

2. (*15 points*) A monochromatic (单色) beam of light of wavelength $589.0\ nm$ is used with a Michelson interferometer. The lengths from the beam splitter to the top mirror (which reflects the vertical beam) and the right-side mirror (which reflects the horizontal beam) are fixed to be $23.0\ cm$ and $18.6\ cm$, respectively.
When a thin piece of fluorite of thickness D and index of refraction $n = 1.434$ is inserted into the horizontal beam midway between the beam splitter and the right-side mirror, a shift of 35 fringes (or bright bands) is observed to flow past a pointer on the observation screen for the re-combined beam.
What is D?



3. (*14 points*) Georges Seurat was a famous neoimpressionist painter of the so-called pointillist school. His paintings are made of a large number of monochromatic (单色) dots each about $2.50\ mm$ in diameter and with the space between the dots considerably smaller than the dot size. If the viewer stands far enough away, the colors appear to mix and so how the painting looks depends on from where you look at it! Assuming the typical dot color to be $550.0\ nm$, approximately how far away can you be to resolve the dots **(a)** with your $4.00\ mm$-diameter eye pupil;
and **(b)** with a $25.0\ mm$ camera aperture?

4. Consider the following observations of three observers sitting on a train platform watching a fast-moving train pass by. All three observers have properly synchronized (已同步) their watches.

The train is traveling  at $v = 0.600\ c$. ($1\ nsec = 1\ nanosecond = 10^{-9}\ sec$)

Observer A: "I was sitting on a platform bench marked $x = 61.0\ m$ when through the window of the train right in front of me I saw **Evil Student** push a button on a box marked **Destruction Ray**. My watch read $t = 100.0\ nsec$."

Observer B: "I was sitting on a platform bench marked $x = 76.0\ m$ when through the window of the train right in front of me I saw all the homework solution sets Poor Student was holding burst into flame.  My watch read $t = 230.0\ nsec$."

Observer C: "I was sitting on a platform bench  marked $x = 30.5\ m$ when through a window of the train right in front of me I saw all of LAO BI's cloths burn up, leaving him naked. My watch read $t = 160.0\ nsec$."

(a) (*5 points*) What are the coordinates of **Evil Student** pushing the button in the rest frame of the train (x', t')? Assume $(x', t') = (0,0)$ when $(x, t) = (0,0)$.

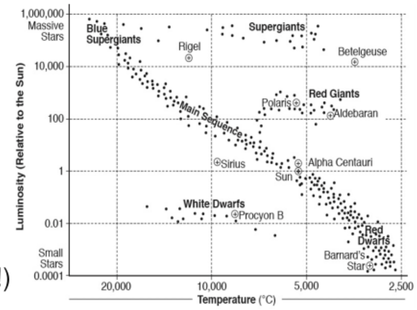
(b) (*5 points*) **Evil Student** has been charged with destroying the solution sets of Poor Student and with offending the train passengers by making LAO BI's clothes burn up. Can you ***show*** that **Evil Student** must be innocent (天真无罪) of either of these two charges?

(c) (*4 points*) Find a train speed for which the **Destruction Ray** button is pushed at the same *time* in the train's rest frame as one of the other events.

(d) (*4 points*) Find a train speed for which the **Destruction Ray** button is pushed at the same *place* in the train's rest frame as one of the other events.

5. (*14 points*) A particle of (rest) mass m moving along the x-axis with velocity v collides with a particle of (rest) mass $\frac{1}{2}m$ moving along the x-axis with a velocity $-v$. This results in the formation of one new particle. What is the rest mass of this newly-formed particle? Check that this gives the expected result for $v \ll c$.

6. Perhaps you never noticed this, but Lao Bi (老毕) is actually a "waiguo ren" – that is, an alien. He originally comes from the Planet Bi-merica that orbits the star LaoBidius Centauri, which is located 50.9 *light-years* from the Earth. A satellite in orbit above the Earth's atmosphere measures the flux of light (integrated over all wavelengths) from LaoBidius Centauri to be $1.70 \times 10^{-8}\ J/s/m^2$ with the spectrum peaking in intensity at a wavelength of $706.829\ nm$.



(a) (*5 points*) Determine the surface temperature and luminosity of LaoBidius Centauri.

(b) (*2 points*) Sketch the H-R (Hertzsprung-Russell) Diagram shown here on your answer sheet, and then mark the location of LaoBidius Centauri on the H-R diagram.

(c) (*4 points*) What is the radius of the star LaoBidius Centauri in units of the solar radius? (Note that data for our solar system is given on the formula sheet.)

Suppose the Planet Bi-merica has the same geometrical size as the Earth, and that Bi-merica is located 42.0 A.U. from LaoBidius Centauri.

(d) (*5 points*) Estimate the average surface temperature on the Planet Bi-merica. You can assume the surface of the Planet Bi-merica is at one temperature (lots of wind!) Neglect all other effects due to the atmosphere of the Planet Bi-merica. (Bi-mericans are very clean, just like 老毕 – there is no smog and virtually no "greenhouse effect.")

(e) (*1 point*) Based on your answers above, draw a picture of 老毕 swimming in the lake (湖) near his family home on Bi-merica on a nice summer day.

7. Monochromatic (单色) light illuminates a clean piece of lithium metal placed in a vacuum which acts as a cathode, causing electrons to be emitted. These electrons can then fly to an anode completing a circuit for which a current can be measured, unless a sufficient retarding or stopping potential, V_0, keeps all the electrons from reaching the anode. For different wavelengths of light, different V_0 are determined, as

$\lambda\ (nm)$	253.5	312.5	365.0	404.7	433.9
$V_0\ (Volts)$	1.23	0.81	0.56	0.39	0.30

(a) (*6 points*) *From this data*, what is the value of Planck's constant? Note: this will **NOT** agree with the value given on the formula sheet.

(b) (*5 points*) According to this data, what is the work function for lithium?

(c) (*5 points*) If the work function for lead (Pb) is $1.47\ eV$, then which of the wavelengths listed in the table above will NOT result in the emission of electrons from a clean lead surface?

8. (*15 points*) A particle is on a table in a uniform gravitational field. The particle is not allowed to fall off the table. The potential energy is $U = mgz$, where $z = 0$ at the table ($g = 9.80\ m/s^2$). Classically, what is the particle's minimum energy? Now, NOT classically, assume the particle moves in a small range z above $z = 0$, with its average height being $\bar{z} = \frac{1}{2}\Delta z$. Give formulæ for E_{min} and $\bar{z}_{min}$, and also numerical values (in units of J & eV, and mm, respectively) for a dust speck of mass $10^{-6}\ g$ and for an electron.

9. Imagine a different universe in which Coulomb's Law is $\vec{F} = \dfrac{Kq_1q_2}{r^{2.5}}\hat{r}$, where $K = 58700.0\ N\,m^{2.5}/C^2$.

(a) (*8 points*) Assuming everything else and all other constants in this different universe are the same as in our Universe, derive a formula for the energy levels of hydrogen in this different universe.

(b) (*3 points*) In units of eV, what is the ionization energy of hydrogen in this universe?

(c) (*5 points*) Draw and energy level diagram for hydrogen in this different universe. Give energies for the five lowest-energy states in units of eV.

(d) (*3 points*) Indicate clearly on your diagram which transitions (if any) are in the visible region of the EM spectrum. Assume the visible region runs from $430.0\ nm$ to $690.0\ nm$.

Notes: you may find doing the numerical calculations interesting; you will also need to maintain at least 3 digit precision.

10. **(a)** (*3 points*) By fitting de Broglie standing waves in a 1-dimensional box of size L, derive a formula for the energy levels for non-relativistic particles in the box (potential energy = 0 inside the box).

The element goop, whose atomic number is 167, has only been produced by scientists on the planet Bi-merica.

(b) (*4 points*) Suppose 40 gloop atoms are confined to an infinitely-deep 3-dimensional energy well of size $L \times L \times L$. The mass of a gloop atom is m. If the gloop atoms are spin-1/2 fermions, what is the Fermi energy for the gloop atoms in the well?

Caution: formulæ derived in lecture and in the text assuming N is very large will not be valid for this problem.

(c) (*2 points*) If the system is in its lowest energy state, what are the system's total energy E_{tot} and the average energy E_{ave} of a gloop atom?

(d) (*2 points*) What is the minimum energy that the system in its lowest energy state can absorb?

(e) (*4 points*) If instead the 40 gloop atoms were bosons, what would be the total energy of the system in its lowest energy state, and what is the minimum energy that the system in its lowest energy state could absorb?

(f) (*2 points*) If quantum states are filled as expected in the simple picture we developed (which is not true), what would be the electronic configuration of the ground state of a gloop atom (do not use any abbreviations!) ?