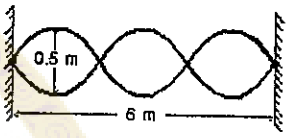
1. A uniform disk, of mass *M* and radius *R*, rolls from rest down a ramp which has a fixed angle θ with respect to the ground. Find out the frictional force on the disk as it rolls down the ramp. You should use *g* to denote the gravitational acceleration in your answer. **[10 pts]**
2. A house has a flat roof with area *A*. There is a pipe with a cross-sectional area, *a*, to collect the rain falling on the roof. The same pipe also runs under the kitchen with a small drain hole to collect the cleaning water on the kitchen floor. If the vertical distance between the roof and the kitchen floor is *H*, estimate what is the critical rainfall rate (meter per second in SI unit) that can threaten to flood the kitchen? Use *g* to denote the gravitational acceleration. **[10 pts]**
3. A uniform spring having mass *m*, spring constant *k* and natural length *L*, is placed on the ground. One of its ends is fixed on the wall and the other end is pulled out by *a* with an external force *F*, i.e. *F=ka*. Assuming no frictional/dissipative force involved, determine the oscillation frequency of the above spring after the external force being removed. **[10 pts]**
4. What is the functional form of a standing wave with a frequency of 100 Hz and an amplitude of 0.25 m, shown in the right figure? The two ends of the string is fixed at x=0 and x=6 (in meter). **[10 pts]**



5. One mole of an ideal monatomic gas with an initial pressure of 5.0 kPa and an initial temperature of 600 K, expands to a final volume V_f=2.0 m^3 with a final pressure of 1.84 kPa. What is the change of entropy of this gas? You should use the universal gas constant *R* and the natural log function in your answer. [10 pts]
6. **(a)** Electron was discovered by J. J. Thomson in 1897. Please describe the experiment using a drawing and equations. The drawing can be a modern version, not necessarily Thomson's original apparatus. [4 pts] Why his discovery is significant? **[1 pts] (b)** Please describe the oil drop experiment, the first determination of elementary charge of electricity, using drawing(s) and/or equations. [4 pts] Why the discovery is significant? [1 pts]
7. **(a)** Derive potential due to an electric dipole. **[3 pts] (b)** What is law of refraction? **[1 pts]** Prove it. **[3 points] [Hint:** Use Huygens principle or Fermat principle.**] (c)** Please briefly describe why the resistivity of metal typically increases as temperature is increased (near room temperature) while the resistivity of semiconductor decreases as temperature is increased. **[3 pts]**
8. **(a)** Please summarize the four basic equations of electromagnetism and give crucial experiments from which the equations were derived and/or which support the equations: Gauss' law for electricity; Gauss's law for magnetism; Faraday's law of induction; Ampere's law. **[8 pts] (b)** An argument of symmetry reveals an important term missing from one of the equations. What is the equation? **[1 pts] (c)** What did Maxwell do to the equation with the missing term? **[1 pts]**
9. **(a)** In Ampere's law, there is a constant μ_0, known as the ***permeability*** constant or the ***magnetic*** constant. In Gauss' law, there is a constant ε_0, known as the ***permittivity*** constant or the ***electric*** constant. Please do the calculation of $(\mu_0\varepsilon_0)^{-1/2}$ and compare it with the ***speed of light***. **[10 pts]**
10. **(a)** Describe the Hall effect, which provides a way to determine both the sign and the density of the charge carriers? **[5 pts] (b)** Derive the Hall voltage as a function of the applied magnetic field. **[3 pts]** [Hint: the moving charges in a conductor (or semiconductor) can be deflected by a magnetic field. The drift speed of the charges is v_d = j/ne, where j is the current density in the strip, and n is the density of charge carriers.] **(c)** What is the quantized Hall effect? **[2 pts]** [Hint: you may draw a curve of Hall resistance versus the applied magnetic field.]

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