1. (15%) A force $F(x)$ acts on a particle that moves along an x axis. The potential energy associated with force $F(x)$ is given by $U(x) = 2x^2 + 3$ J.

(a) (7%) Plot $F(x)$ for the range $-3 \le x \le 3$ m.

(b) (3%) Plot $U(x)$ for the range $-3 \le x \le 3$ m.

(c) (5%) Suppose the mechanical energy E_{mec} of the system is 21 J, describe the motion of the particle.

2. (15%) Block A of mass $3M$ and block B of mass M are in contact on a frictionless table. A horizontal force $\boldsymbol{F}$ is applied to block A as shown in Fig. 2a.

(a) (5%) Find the magnitude of the force between the two blocks.

(b) (5%) If a force of the same magnitude $\boldsymbol{F}$ is applied to block B but in the opposite direction as shown in Fig. 2b, find the magnitude of the force between the two blocks.

(c) (5%) Explain why the results of (a) and (b) are different.

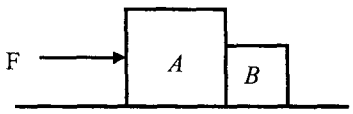

Fig. 2a

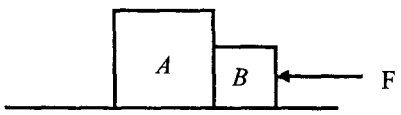

Fig. 2b

3. (20%) The equation to describe a sinusoidal wave on a stretched string is

$$y(x,t) = y_m \sin(kx - \omega t)$$

(a) (3%) Describe y_m, k, and ω.

(b) (3%) Does any element on the string move along x direction? If yes, describe the motion.

(c) (3%) Does any element on the string move along y direction? If yes, describe the motion.

(d) (6%) The wave $y_2(x,t)$ differs from $y(x,t)$ by the following properties: the wavelength of wave $y_2(x,t)$ is half of $y(x,t)$ and the wave speed of $y_2(x,t)$ is 4 times larger than that of $y(x,t)$. Write down the equation of wave $y_2(x,t)$

(e) (5%) Describe **in words** how to construct a standing wave on a stretched string?

4. (20%) N moles of an ideal gas undergoes a free expansion as shown in Fig. 4.

(a) (10%) Calculate the change in entropy using its definition.

(b) (10%) For the same problem, calculate the change in entropy using Boltzmann equation of entropy (or Boltzmann's entropy equation).

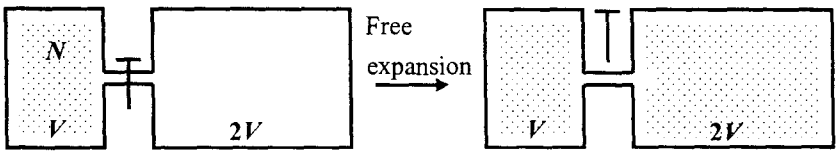

Fig. 4. V and $2V$ are the volumes of the two containers.

5. (20%) A parallel-plate capacitor of capacitance C with circular plates of radius R is charging in Fig. 5. The plates are separated by a distance d. $B_1(r)$ is the magnetic field around the wire, where r is the perpendicular distance from the wire. $B_2(r')$ is the magnetic field around the capacitor, where r' is radial distance from the center of the capacitor.

(a) (5%) Write down the Maxwell's equation that is used to find $B_1(r)$, and explain the physical meaning of that equation.

(b) (5%) Write down the Maxwell's equation that is used to find $B_2(r')$, and explain the physical meaning of that equation.

If the charge $q(t)$ on the plates is given by $q = q_0(1-e^{-t/\tau})$, where τ is a time constant,

(c) (5%) find $B_1(r)$

(d) (5%) find $B_2(r')$ for $r' > R$

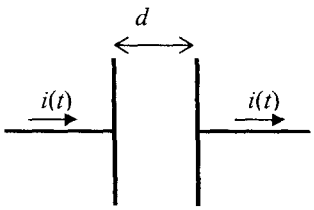

Fig. 5

6. (10%) The matter wave of a particle is described by a wave function $\psi = \psi_o e^{ikx}$.

(a) (4%) Plot the probability density of this particle as a function of x.

(b) (6%) Where can this particle be found most likely? Discuss this result in terms of Heisenberg's uncertainty principle.