Problem 1 (2.5 points) **Answer on Scantron form**

In what year was the Royal Dutch Airlines born?

Figure 1: Adverisement for the KLM in the USA in 1982.

1. 1823.
2. 1900.
3. 1905.
4. 1909.
5. 1914.
6. **1919**.
7. 1923.
8. 1925.
9. 1928.
10. 1982.

Option 6 is the correct answer.

Problem 2 (2.5 points) **Answer on Scantron form**

When Freddy Flyweight stands at rest on a scale in the gym, it reads 500 N. Now he stands on an identical scale in an elevator that accelerates upward at 1 m/s^2, as shown in Fig. 2.

Figure 2: Freddy Flyweight in an accelerating elevator.

Consider the following three statements:

(a) Freddy is pulling the Earth upward with a force of 500 N.
(b) During the acceleration, the scale reads 550 N.
(c) Freddy is pushing down on the scale with a force of 550 N.

What do you conclude about statements (a), (b), and (c)?

1. None of the statements (a), (b), and (c) is correct.
2. One of the statements (a), (b), and (c) is correct.
3. Two of the statements (a), (b), and (c) are correct.
4. **All of the statements (a), (b), and (c) are correct.**

Option 4 is the correct answer.

Problem 3 (2.5 points) **Answer on Scantron form**

Figure 3 shows a portion of a graph of energy vs. time for a mass on a spring, subject to air resistance.

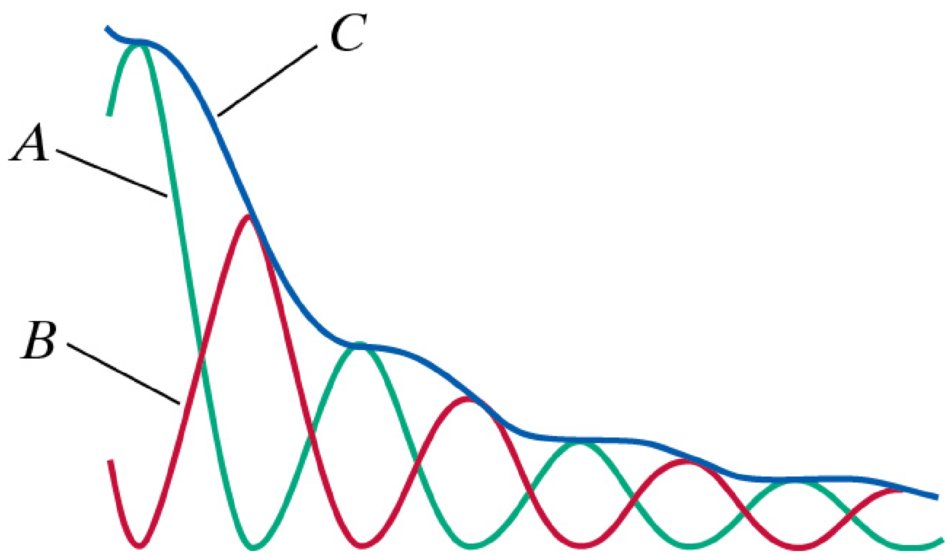

Figure 3: Energy curves for a mass on a spring.

Identify the three curves as to what kind of energy each represents.

1. A = Kinetic energy, B = Potential energy, C = Total energy.
2. A = Kinetic energy, C = Potential energy, B = Total energy.
3. B = Kinetic energy, C = Potential energy, A = Total energy.
4. **B = Kinetic energy, A = Potential energy, C = Total energy.**
5. C = Kinetic energy, A = Potential energy, B = Total energy.
6. C = Kinetic energy, B = Potential energy, A = Total energy.

Option 4 is the correct answer.

Problem 4 (2.5 points) **Answer on Scantron form**

Figure 4 shows the potential energy distribution of a star-planet system. Three different types of motion of the planet are represented by the three energy states indicated (*A*, *B*, and *C*).

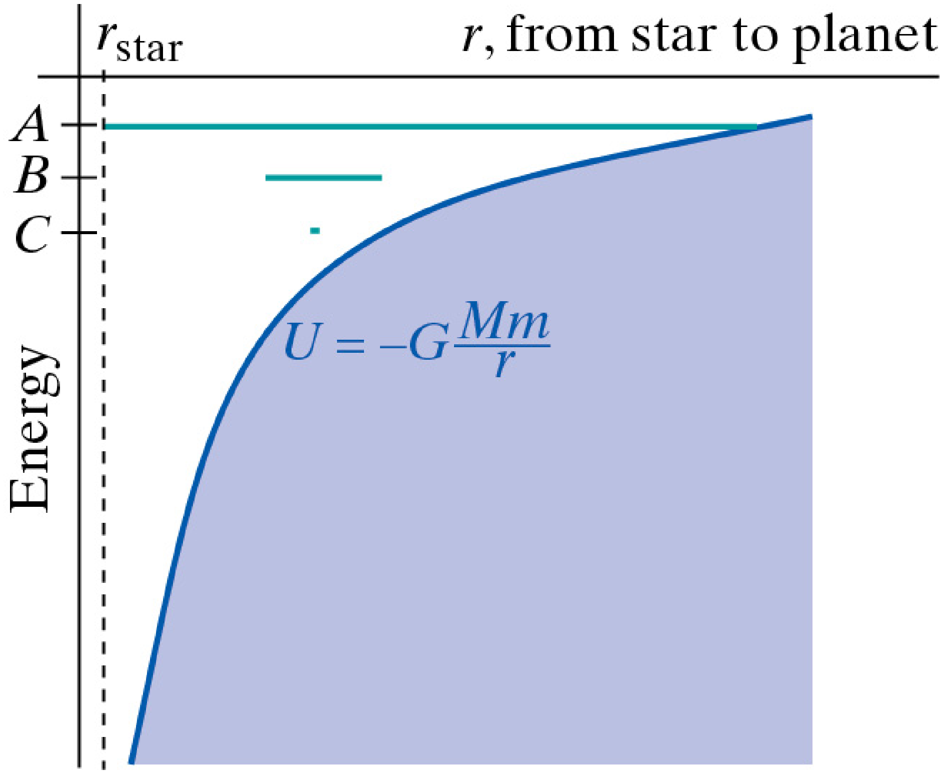

Figure 4: The potential energy distribution of a star-planet system

Which of these states represents the planet in an elliptical orbit?

1. *A*.
2. *B*.
3. *C*.

Option 2 is the correct answer.

Problem 5 (2.5 points) **Answer on Scantron form**

Figure 5 shows the path of a comet orbiting a star.

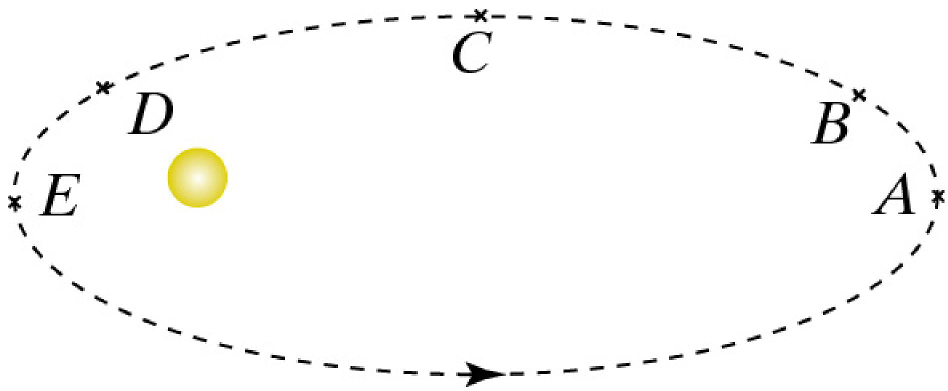

Figure 5: The path of a comet orbiting a star.

At what location on the path has the comet its lowest kinetic energy?

1. **A.**
2. B.
3. C.
4. D.
5. E.

Option 1 is the correct answer.

Problem 6 (2.5 points) **Answer on Scantron form**

A particle moves inside a circular glass tube under the influence of a tangential force of constant magnitude F, as shown in Fig. 6.

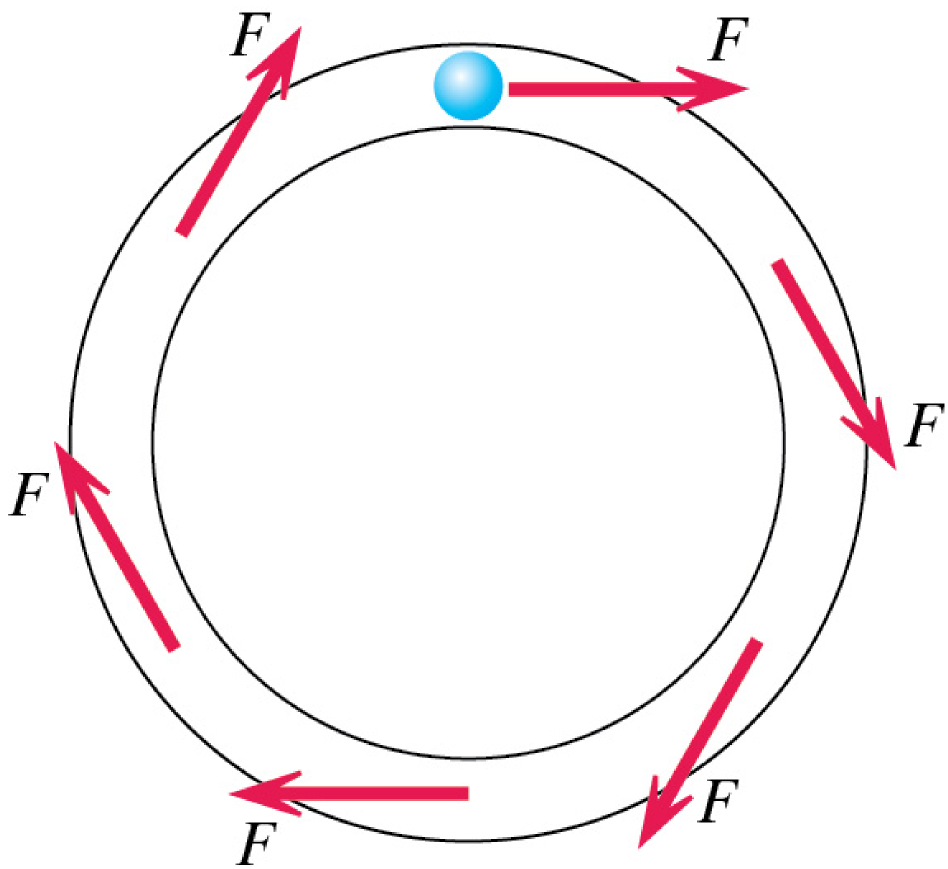

Figure 6: A particle moving in a circular glass tube.

Can we associate a potential energy with this force?

1. Yes.
2. **No.**
3. Insufficient information available to answer this question.

Option 2 is the correct answer.

Problem 7 (2.5 points) **Answer on Scantron form**

Which of the diagrams in Fig. 7 correspond to a system of one electron and one positron that start out far apart, moving straight towards each other with nonzero initial velocities?

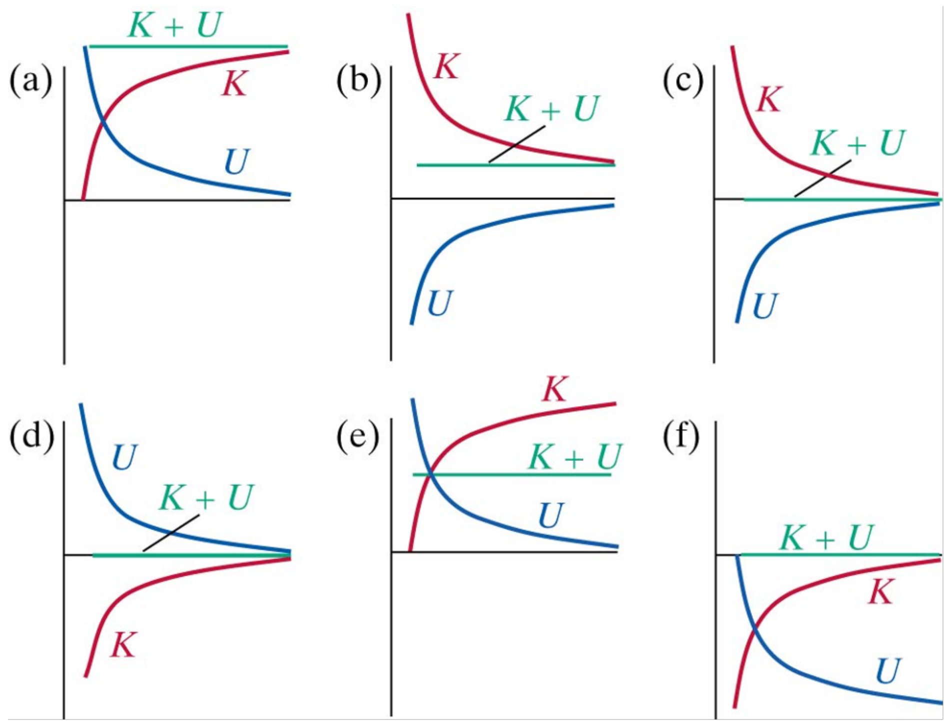

Figure 7: Kinetic, potential, and total energy of an electrons and positron system.

1. (a).
2. **(b).**
3. (c).
4. (d).
5. (e).
6. (f).

Option 2 is the correct answer.

Problem 8 (2.5 points) **Answer on Scantron form**

Two wires with equal lengths are made of pure copper. The diameter of wire A is twice the diameter of wire B. When 6-kg masses are hung on the wires, wire B stretches more than wire A. You make careful measurements and compute the Young's modulus for both wires. What do you find?

1. $Y_A > Y_B$.
2. $Y_A = Y_B$.
3. $Y_A < Y_B$.

Option 2 is the correct answer.

Problem 9 (2.5 points) **Answer on Scantron form**

You have two identical springs, connected in parallel. When you hang a mass m from this system, as shown in Fig. 8, the new equilibrium position of the system is a distance d below the equilibrium position when no mass is connected to the system.

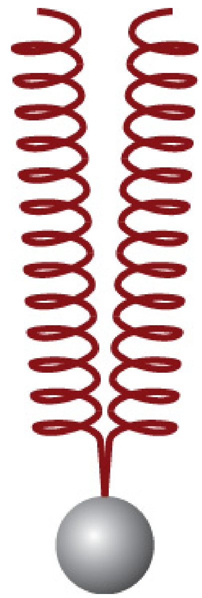

Figure 8: A parallel spring system.

Now you connect the two springs in series. The system is in equilibrium when you connect mass m to the end of the lower spring. What is the displacement of mass m when it has reached its new equilibrium position?

1. $4d$
2. $2d$
3. $\sqrt{2}d$
4. d
5. $d/\sqrt{2}$
6. $d/2$
7. $d/4$

Option 1 is the correct answer.

Problem 10 (2.5 points) **Answer on Scantron form**

Two springs with spring constants k_1 and k_2 are connected as shown in Fig. 9.

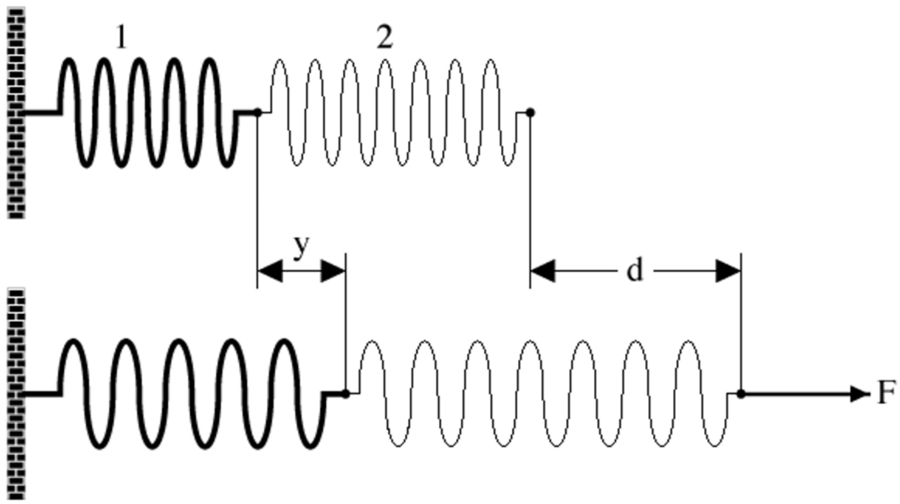

Figure 9: Two springs in series.

What is the displacement y of the connection point from its initial equilibrium position when the two springs are stretched a distance d as a result of the application of force F.

1. $y = d\frac{k_1}{k_1+k_2}$
2. $y = d\frac{k_1}{k_2}$
3. $y = d\frac{k_2}{k_1+k_2}$
4. $y = d\frac{k_2}{k_1}$
5. d

Option 3 is the correct answer.

Problem 11 (25 points) **Answer in booklet 1**

The Stanford Linear Accelerator Center (SLAC), located at Stanford University in Palo Alto, California and shown in Fig. 10, accelerates electrons through a vacuum tube of length L.

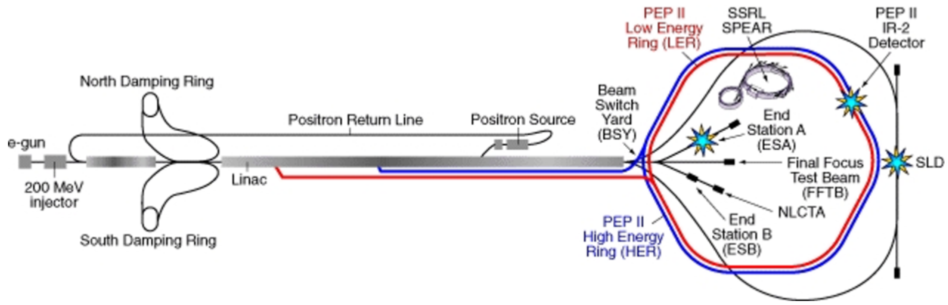

Figure 10: The Stanford Linear Accelerator Center (SLAC)

Electrons of mass m, which are initially at rest, are subjected to a continuous force F along the entire length L of the tube and reach speeds very close to the speed of light

(a) Calculate the final energy of the electrons.

The work done by the force F is FL, where L is the length of the accelerator. Using the work-energy theorem, we can express the final energy of the electron in terms of its initial energy and the work done by F:

$$E_f = E_i + FL = mc^2 + FL \tag{1}$$

(b) Calculate the final momentum of the electrons.

The final momentum of the electron can be obtained using the following relation:

$$E^2 - p^2c^2 = \left(mc^2\right)^2 \tag{2}$$

or

$$p_f = \frac{1}{c}\sqrt{E_f^2 - (mc^2)^2} = \frac{1}{c}\sqrt{(mc^2 + FL)^2 - (mc^2)^2} = \frac{FL}{c}\sqrt{1 + 2\frac{mc^2}{FL}} \tag{3}$$

(c) Calculate the final speed of the electrons.

The final velocity of the electron can be found using the following relation:

$$E = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}} \tag{4}$$

and is equal to

$$v = c\sqrt{1 - \left(\frac{mc^2}{E_f}\right)^2} = c\sqrt{1 - \left(\frac{mc^2}{mc^2 + FL}\right)^2} \tag{5}$$

(d) Calculate the time required to travel the distance L.

The time required to complete the trip through the accelerator can be found by using the momentum principle:

$$\Delta t = \frac{\Delta p}{F} = \frac{p_f - p_i}{F} = \frac{p_f}{F} = \frac{L}{c}\sqrt{1 + 2\frac{mc^2}{FL}} \tag{6}$$

Problem 12 (25 points) **Answer in booklet 1**

There is an amusement park ride that some people love and others hate. A bunch of people stand against the wall of a cylindrical room of radius R and the room starts to rotate at higher and higher speed (see Fig. 11). The surface of the wall is designed to maximize friction between the person and the wall. When a certain critical speed is reached, the floor drops away, leaving the people stuck against the wall as they whirl around at constant speed.

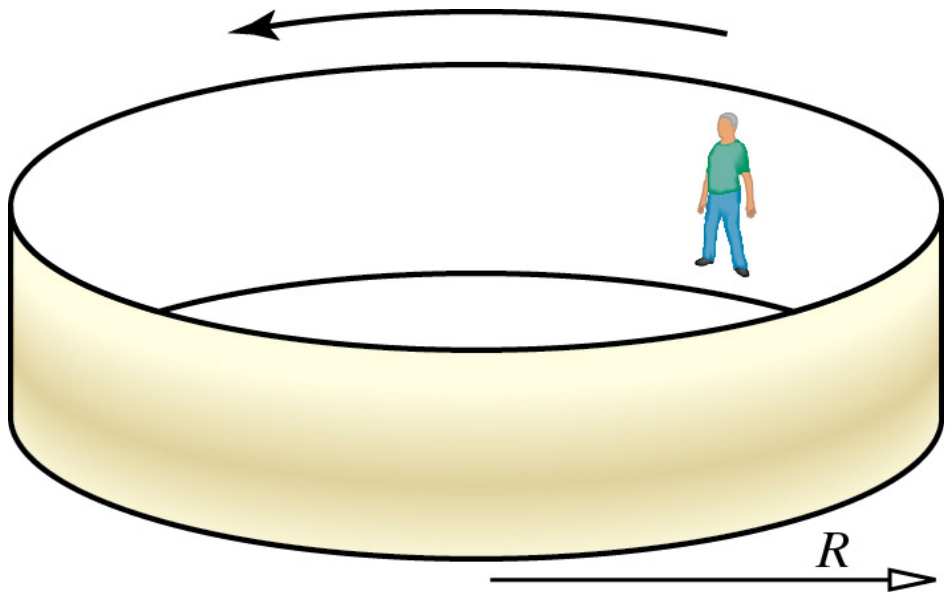

Figure 11: An amusement park ride.

(a) If the critical speed is v, what is the minimum value of the static friction coefficient between the wall and the people that will ensure that they do not slide down the wall when the floor drops?

The forces acting on a person are shown in Fig. 12.

In order for the person not to slide down the wall, the friction force must have the same magnitude as the gravitational force acting on the person. This requires that

$$\left|\vec{f}_{friction}\right| = \left|\vec{F}_{grav}\right| = mg \tag{7}$$

In order for the person to carry out circular motion, a radial force must be present, directed towards the center of the circle, with a magnitude equal to mv^2/R. The only force that can satisfy this requirement is the normal force, exerted by the wall on the person. The normal force must thus be equal to

$$\left|\vec{F}_N\right| = \frac{mv^2}{R} \tag{8}$$

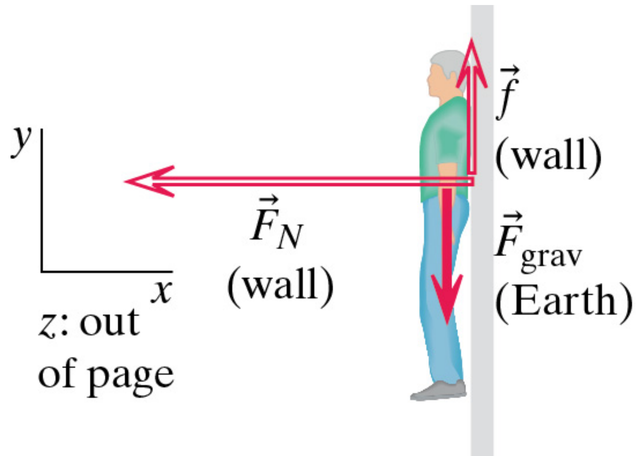

Figure 12: An amusement park ride.

The normal force limits the static friction force between the person and the wall. We thus conclude that

$$\left|\vec{f}_{friction}\right| = mg \le \mu_s \left|\vec{F}_N\right| = \mu_s \frac{mv^2}{R} \tag{9}$$

or

$$\mu_s \ge \frac{mg}{\frac{mv^2}{R}} = \frac{gR}{v^2} \tag{10}$$

(b) What happens to the minimum value of the static friction coefficient when the speed doubles to $2v$?

The answer to part a) shows that when the speed doubles, the minimum value of the static friction coefficient decreases by a factor of 4.

Problem 13 (25 points) **Answer in booklet 2**

Figure 13 shows the potentials energy between two neutral atoms as function of their separation distance. The two atom system is in a vibrational state indicated by the solid horizontal line in Fig. 13.

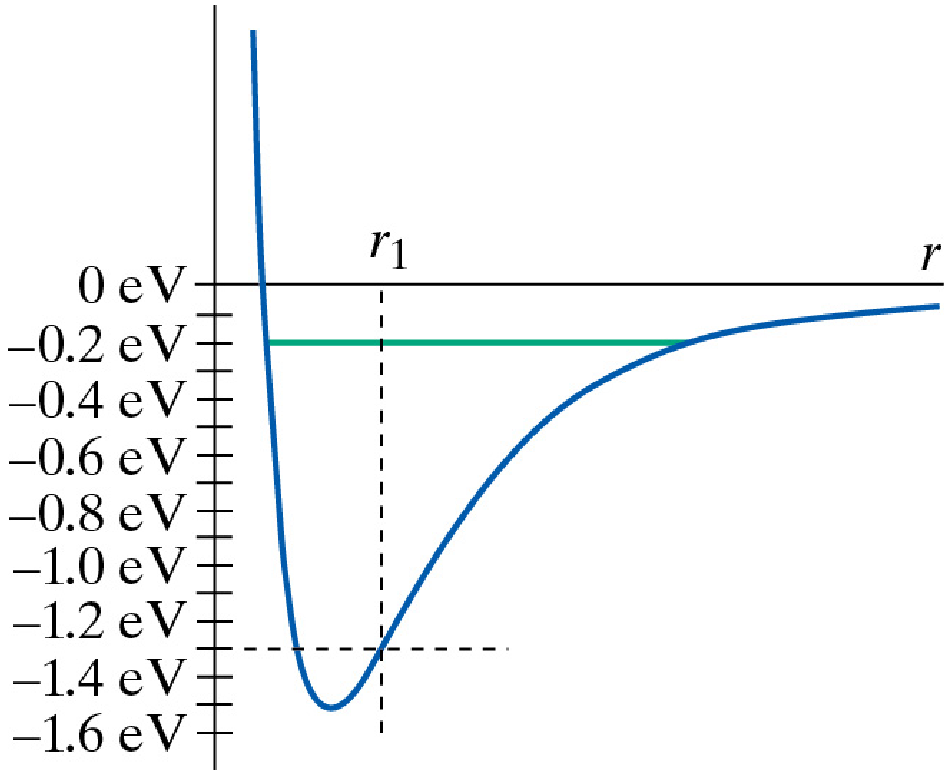

Figure 13: Potential energy between two neutral atoms as function of their separation distance.

(a) At $r = r_1$, what are the approximate values of the kinetic energy K, the potential energy U, and the quantity $K + U$?

At r_1 the potential energy U is -1.3 eV. The total energy $E = K + U$ of the two atoms is indicated by the solid horizontal line in Fig. 13 and is equal to -0.2 eV. The kinetic energy K of the system is thus equal to $(K + U) - U$ = -0.2 eV - (-1.3 eV) = 1.1 eV.

(b) What minimum energy must be supplied to cause these two atoms to separate?

In order for the atoms to separate, they should be able to reach infinity where the inter-actomic potential energy is 0 eV. In order to reach infinity, the total energy of the atoms must be at least 0 eV, and the energy that must be supplied is thus 0.2 eV.

(c) In some cases, when r is large, the inter-atomic potential can be expressed approximately as $U = -a/r^6$. For large r, what is the force the two atoms exert on each other? **Note: you must specify the magnitude and the direction of the force.**

The force can be obtained using the following relation between force and potential energy:

$$F = -\frac{dU}{dr} = -\frac{d}{dr}\left(\frac{-a}{r^6}\right) = -\left(\frac{6a}{r^7}\right) \tag{11}$$

The force is directed towards the left (towards smaller value of r) and has a magnitude of $6a/r^7$.