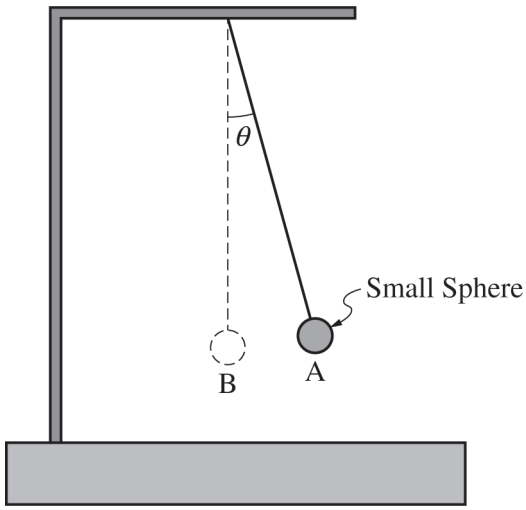
Begin your response to **QUESTION 4** on this page.



4. (7 points, suggested time 13 minutes)

A simple pendulum consists of a small sphere that hangs from a string with negligible mass. The top end of the string is fixed. The sphere is pulled to Point A so that the string makes a small angle θ with the vertical, as shown. The sphere is then released from rest and swings through its lowest point at Point B. The work done on the sphere by Earth between points A and B is W_E.

The pendulum is then taken to Planet X. The mass of Planet X is the same as the mass of Earth, but the radius of Planet X is greater than the radius of Earth. The sphere is again brought to Point A (displaced θ from the vertical), released from rest, and swings through its lowest point at Point B. The work done on the sphere by Planet X between points A and B is W_X.

(a) **Justify** why W_X is less than W_E.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 4** on this page.

A new pendulum is made by hanging the same small sphere from a different string with negligible mass. The new string is slightly elastic, and the length of the string may increase or decrease depending on the tension applied to the string. On Earth, when the sphere is again displaced θ from the vertical and released from rest, the new pendulum oscillates with period T_E.

The new pendulum is then taken to a different planet, Planet Y. The radius of Planet Y is the same as the radius of Earth, but the mass of Planet Y is larger than the mass of Earth. On Planet Y, when the sphere is again displaced from the vertical and released from rest, the new pendulum oscillates with period T_Y.

(b) In a clear, coherent paragraph-length response that may also contain drawings, **explain** how T_Y could be larger than T_E but also could be smaller than T_E.

GO ON TO THE NEXT PAGE.

Question 4: Paragraph — 7 points

(a) For indicating **one** of the following: **1 point**

- That the gravitational force would be smaller for a greater radius
- That the gravitational field strength would be smaller for a greater radius
- That the acceleration due to gravity would be smaller for a greater radius

For indicating **one** of the following: **1 point**

- The sphere travels the same vertical distance in both scenarios
- The amount of work done on the sphere is dependent on the magnitude of the gravitational force
- The change in gravitational potential energy is less on Planet X

Example Response

The mass is the same and the radius is larger, so the force of gravity is less. The work done depends on the force times distance. Because the distance is the same, the work is less.

Total for part (a) 2 points

(b) For relating a larger planetary mass to a **one** of the following: **1 point**

- A larger weight of the sphere
- A larger acceleration due to gravity g
- A larger gravitational field strength

For indicating that the period is inversely related to **one** of the following: **1 point**

- The acceleration due to gravity g
- The gravitational field strength

For indicating that the amount of stretch is dependent on **one** of the following: **1 point**

- The weight of the sphere
- The acceleration due to gravity g
- The gravitational field strength

For relating the length of the string to the period of the pendulum **1 point**

For a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response **1 point**

Example Response

$T = 2\pi\sqrt{\frac{\ell}{g}}$. *On Planet* Y *the gravitational force on the sphere is larger than when on Earth. Therefore, the sphere will experience a larger acceleration due to gravity on Planet* Y*. Because "g" is in the denominator of the equation, a larger acceleration due to gravity leads to a potentially smaller period. However, the increased gravitational force exerted on the sphere by Planet* Y *could result in the string stretching. This could result in the length of the pendulum increasing. Because* T *increases with the length of the pendulum, a longer string could potentially lead to a larger period.*

Total for part (b) 5 points

Total for question 4 7 points