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1. Write down the three kinematic equations of motion of a free particle with initial velocity $\vec{v}_0 = (0, 0, 3)$ m/s and initial position $\vec{x}_0 = (2, -4, -1)$ m with respect to some observer.

2. What is the position (i.e position vector) of the particle at $t = 4$ s?

3. How far away is the particle from the observer (i.e what is the distance from the observer to the particle) at $t = 4$ s?

4. How do the kinematic equations of motion look like for the particle from the previous exercise if we choose our frame of reference to be at the location of the particle at $t = 0$, and the frame itself moving at a constant velocity of $\vec{v}_{\text{frame}} = (0, 0, 3)$ m/s. Note that this is also a good inertial frame of reference.

5. In the following exercises we will apply Newton's theory to a different kind of motion: **projectile motion**. Newton tells us that a flying projectile near the earth's surface is subject to the force of gravity $\vec{F}_g = m(0, -9.8)$ for an observer whose y axis points upwards. Apply Newton's second law to the projectile (neglecting air resistance) and **calculate the acceleration** of the projectile of mass m that's flying near the surface of the earth. Does this acceleration change if we change the mass of the object?

6. Once we have the acceleration, we applied calculus (integrals) to derive the remaining kinematic equations for the projectile motion. The result was

$$\vec{v} = \vec{v}_0 + (0, -9.8)t \tag{1}$$

$$\vec{x} = \vec{x}_0 + \vec{v}_0 t + \frac{1}{2}(0, -9.8)t^2 \tag{2}$$

Because projectile motion happens in two dimensions, a two dimensional grid will suffice to describe the position and velocity vectors. If $\vec{x}_0 = (1, 3)\ m$ and $\vec{v}_0 = (2, 3)\ m/s$, how will the equations above look like? Write the equation for each component separately.

$$v_x = \tag{3}$$

$$v_y = \tag{4}$$

$$x = \tag{5}$$

$$y = \tag{6}$$

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7. Open the following online simulator: https://phet.colorado.edu/sims/html/projectile-motion/latest/projectile-motion$_e n.html$ Shoot the projectile at an initial velocity of $\vec{v}_0 = (10, 0)\ m/s$ from a height of 10 m. What is the range and time when it hits the ground? (the simulator has a device for measuring time, range and height at any point of the trajectory, use that) Attach a screenshot showing the path of the cannonball.

8. We could have used equation (2) (or equivalently equations (5) and (6)) to predict the range and time when the cannonball hits the ground in exercise 7 (using the initial position and velocity from exercise 7). Can you derive the range and time **from equation (2) alone** and verify that it is the same as what you measured in the simulation?

9. Now repeat the shot at a higher speed **without changing the inclination of the cannon**. Does the cannonball take more, less or the same time to hit the ground if we increase the initial horizontal speed?

10. Now, **keeping the initial speed constant and the cannon on the ground** level, shoot the cannonball with different inclinations. What inclination angle gives you the maximum range? Attach a screenshot of your simulation "experiment".