

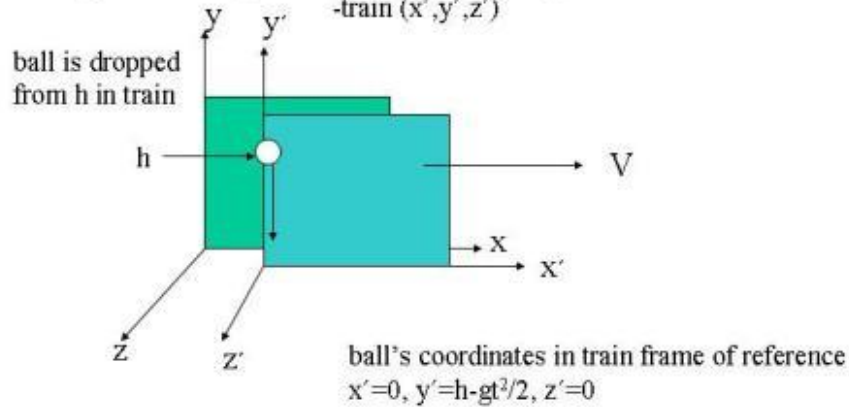
1. Relativity of motion

### Relativity of motion

Consider a ball dropped in a moving train. What happens?

Set up coordinate systems -station platform (x,y,z)

-train (x',y',z')



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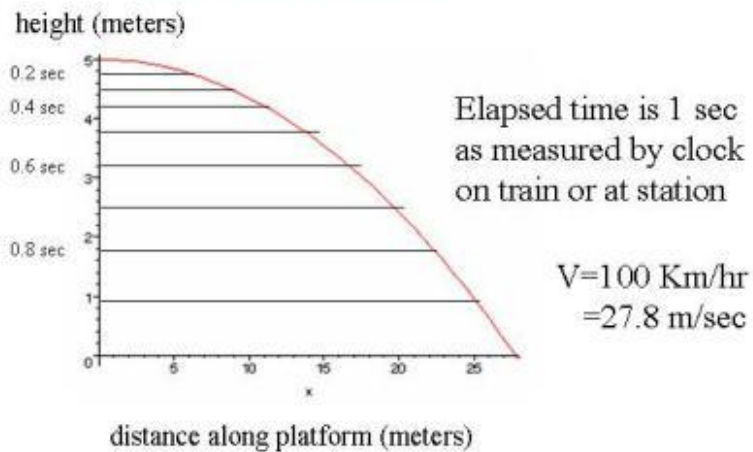
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2. Falling ball

### Falling ball on 100 Km/hr train as seen from platform Drop from 5 meters



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### 3. Review of Classical Motion

#### Review of Classical Motion

- Idealize - isolated **particle** motion.
- Description must be quantitative. Specify measurable quantities - position and time.
- Coordinates & units - reference origin.
- Change of position or displacement vs. time is motion.
- Rate of change of displacement is speed or velocity.

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### 4. Car example

#### Car example

- Car going 40 mph North (vector) =  $v$   
Would go 40 miles N in 1 hour  
80 miles N in 2 hours if constant or uniform  
This is 1 dimensional. Just need distance  $x$  and time  $t$ .

How far in 5 min?

$$t = \frac{5 \text{ min}}{60 \frac{\text{min}}{\text{hr}}} = \frac{1}{12} \text{ hr}$$

$$\begin{aligned} \text{distance} &= v \times t = 40 \frac{\text{mi}}{\text{hr}} \times \frac{1}{12} \text{ hr} = \frac{40}{12} \text{ mi} \\ &= 10/3 \text{ mi} = 3.3 \text{ mi} \end{aligned}$$

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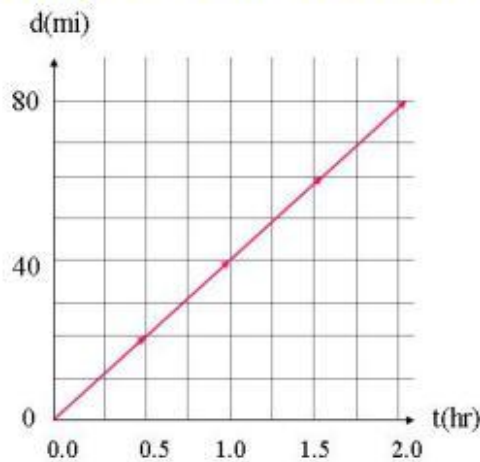
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5. Graph of car motion North

### Graph of car motion North



Linear graph indicates constant, uniform motion

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6. v, d, t relation

### v, d, t relation

- $v$ =speed (velocity),  $d$ =distance traveled,  $t$ =time
- Note equation:  $d = v t$  or  $v = d / t$  or  $t = d / v$
- Other examples:
  - $v=40$  mph car goes 10 miles. How long does it take?  
 $t = d / v = 10 \text{ mi} / (40 \text{ mi/hr}) = 1/4 \text{ hr} = 15 \text{ min}$
  - Another Car travels 20 miles in 20 min. What is its speed?  
 $v = d / t, t = 20 \text{ min} = 20/60 \text{ hr} = 1/3 \text{ hr}, \text{ so}$   
 $v = 20 \text{ mi} / (1/3 \text{ hr}) = 60 \text{ mi/hr (or 60 mph)}$   
Actually could have been non-uniform,  $v$  would be average.
  - Light travels at  $c = 3.0 \times 10^8 \text{ m/s}$ . How far in 5 min?  
 $d = c t = (3.0 \times 10^8 \text{ m/s}) \times (5 \times 60 \text{ s}) = 900 \times 10^8 \text{ m} = 9.0 \times 10^{10} \text{ m}$   
 $= 90 \times 10^6 \text{ Km}$  (~ distance to sun)

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## 7. Newton and acceleration

### Newton and acceleration

- Newton's 1st Law: **body remains in uniform motion unless acted upon by (net) force**
- Non-uniform means **v changes** (magnitude or direction)
- Changing v over time is **acceleration (response to force)**
  - $a = \text{change of } v / t \text{ elapsed}$  or  $v/t$  for constant  $a$
- $F=ma$  Newton's 2nd Law
- **a due to force of gravity =  $9.8 \text{ m/s}^2 = g$  always downward**

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## 8. Acceleration due to gravity

### Acceleration due to gravity

- **a due to force of gravity =  $9.8 \text{ m/s}^2 = g$  always downward**
- **Vertical motion on earth** (gravity alone)
  - downward velocity increases at constant rate ( $v=-gt$ )
  - vertical downward distance increases as  $-\frac{1}{2}gt^2$
  - (over  $t$ , average  $v=-gt/2$  so vertical distance= $v_{\text{ave}}t=-gt^2/2$ )
  - so height of falling object  $y=h - \frac{1}{2}gt^2$
- Dropping height 5.0 meters  $y=5.0-9.8/2 t^2 = 5.0-4.9t^2$  so ball hits ground in  $\sim 1$  sec.
  - that is  $y=0$  implies  $0 = 5.0-4.9t^2 \rightarrow 4.9t^2=5.0 \rightarrow t^2=5.0/4.9=1.02$
  - $\rightarrow t = \sqrt{1.02} = 1.0 \text{ sec}$

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9. Relativity of motion

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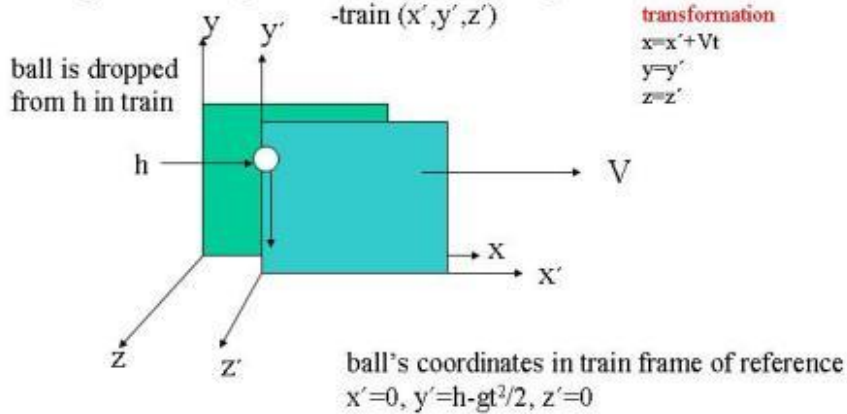
-train (x',y',z')

transformation

$$x = x' + Vt$$

$$y = y'$$

$$z = z'$$



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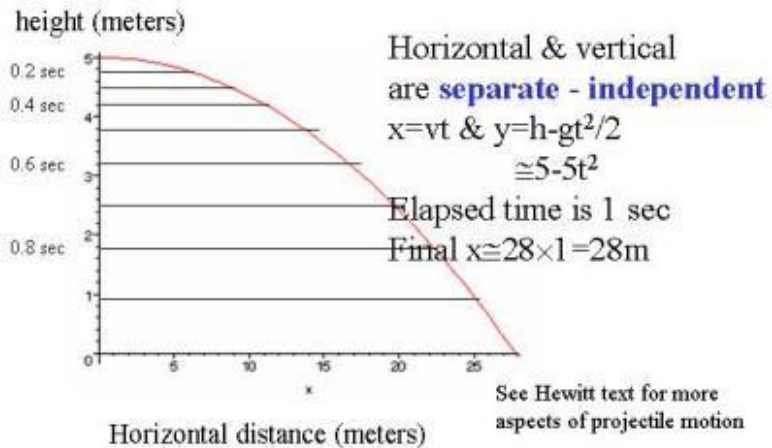
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10. Horizontally thrown ball

### Horizontally thrown ball at height 5 meters

Given:  $v(\text{initially}) = 100 \text{ Km/hr} = 27.8 \text{ m/sec}$  horizontal



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11. Galilean relativity

## Galilean relativity



- Ball seen from platform follows trajectory for initial velocity in x-direction  $v(\text{ball})_x = 100 \text{ Km/hr}$  (note subscript notation)  
=  $V$  of train (initial means at time  $t=0$ )  
and no initial velocity in  $y$  &  $z$  directions
- **No force in x direction**  $F=0 \rightarrow ma=0 \rightarrow a=0 \rightarrow$ 
  - so  $v_x$  of ball unchanged and  $x$  increases  $x = v_x t$
- Gravity in  $-y$  direction, so downward  $v_y$  increases and  $y$  falls from 5 m to 0 via  $y = 5m - gt^2/2$

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12. Galilean relativity (cont'd)

## Galilean relativity (cont'd)

- Acceleration same in either Frame of Reference - none in x-direction &  $-g$  in y-direction
- **So  $F=ma = ma'$**   
Newton's 2nd Law unchanged
- There is no way to determine which Frame of Reference is "at rest" by doing experiments!
- How do you feel in uniformly moving train or plane?
- What about waves in moving water? Or planes flying through air current? Or boat in current? Or sound waves in air?
- There is a medium and a preferred or absolute frame for these waves.

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