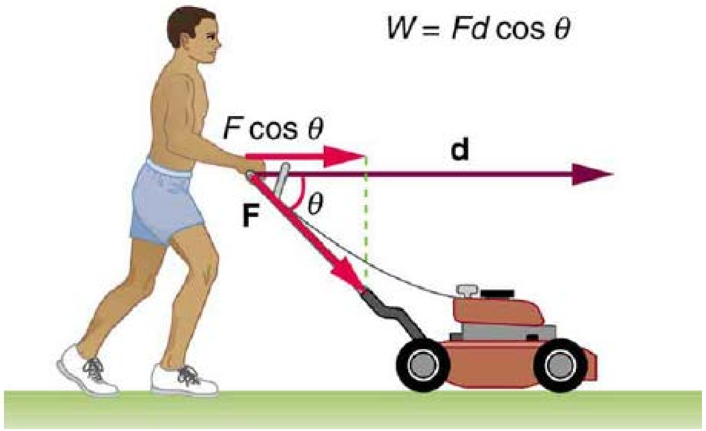
Thursday February 28

Topics for this Lecture:

- *Conservation of energy*
- *Work*
- *Kinetic & Potential Energy*

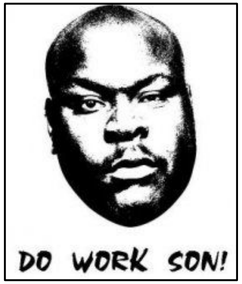
- Assignments 6 ***and*** 7 due Friday
- Pre-class due 15min before class
- Help Room: Here, 6-9pm Wed/Thurs
- SI: Morton 222, Mon&Thurs 7:20-8:10pm
- Office Hours: 204 EAL, 10-11am Wed or by appointment (meisel@ohio.edu)

- Kinetic Energy (KE):
  - Energy corresponding to linear motion
  - $KE = (1/2)mv^2$
- Potential Energy (PE):
  - Stored energy (*many different kinds)
  - From gravity: $PE = mgh$
- Work:
  - Change in KE and/or PE
  - Force required to move an object over a given distance

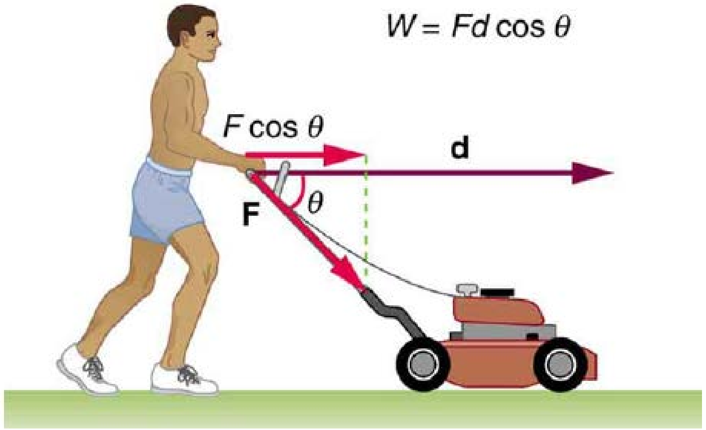


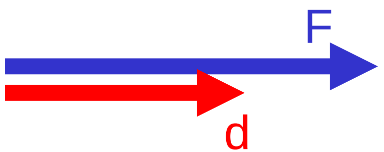
Work: Work done by a force or forces

Christopher Boykin



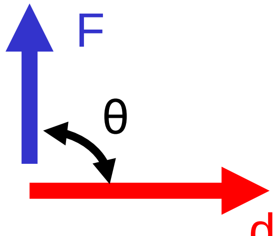
- Work done by a force or group of forces
  - –Work = (mag. of force) (mag. of displacement) (cos θ)
  - –$W = F*d*\cos(\theta)$
- Units of Work and Energy: Joules (J)
- Sign: θ angle between force and displacement
  - – same direction (+)
  - – opposite direction (-)
  - – perpendicular (0)





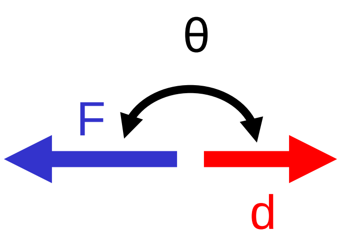
$\theta = 0^{\circ}$

W positive



$\theta = 90^{\circ}$

W zero



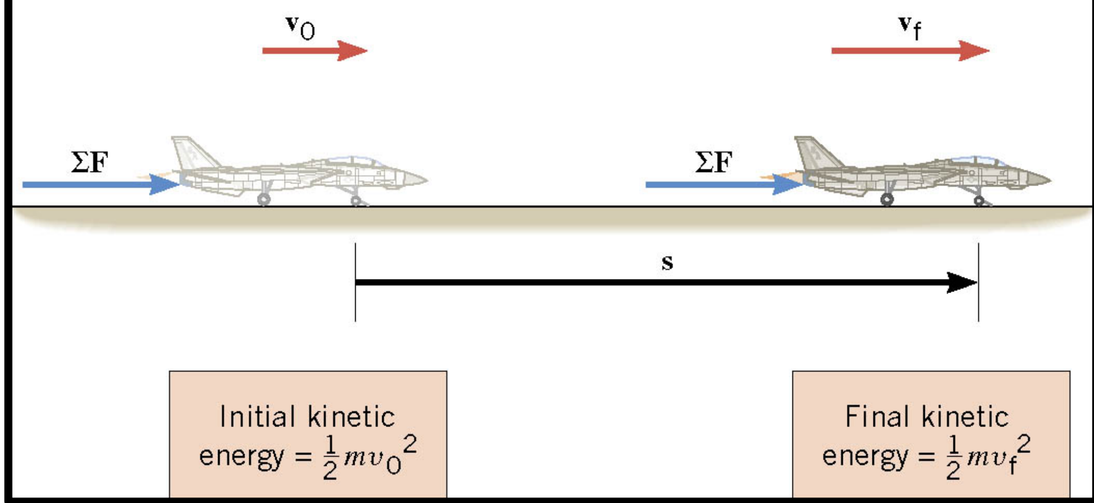
$\theta = 180^{\circ}$

W negative

Work: Net work from changes in kinetic energy

1. Work = $W_{net} = F_{net} \cdot d = ma \cdot d$
2. From 1D-kinematics, recall: $v_f^2 = v_i^2 + 2a(x - x_0) = 2ad$
   1. So: $2ad = v_f^2 - v_i^2$
3. We are free to multiply both sides of (2.1) by mass, m, and divide by 2
   1. $mad = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$
4. Then, we recall that $W_{net} = F_{net} \cdot d = ma \cdot d$
   1. $W_{net} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$
5. Kinetic Energy = $KE = \frac{1}{2}mv^2$
   1. $W_{net} = KE_{final} - KE_{initial}$
   2. $W_{net} = \Delta KE$

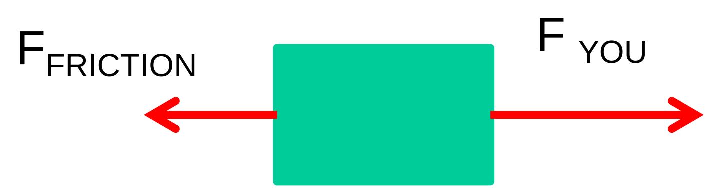
How much work does it take for a jet to take-off?



A crate is moving horizontally across a floor to the right with a kinetic energy of 100J.
You do +300J of work on the crate as it moves 5m.
The magnitude of the work done by the frictional force, which is opposing you, is 150J.
The weight of the crate is 50N.
What is the kinetic energy of the crate after moving 5m?

(A) 50J (B) 100J (C) 200J **(D) 250J** (E) 350J

1. $W_{NET} = 300J - 150J = +150J$
2. $W_{NET} = \Delta KE$
3. $W_{NET} = KE_{FINAL} - KE_{INITIAL}$
4. $KE_{FINAL} = KE_{INITIAL} + W_{NET}$
5. $KE_{FINAL} = 100J + 150J$



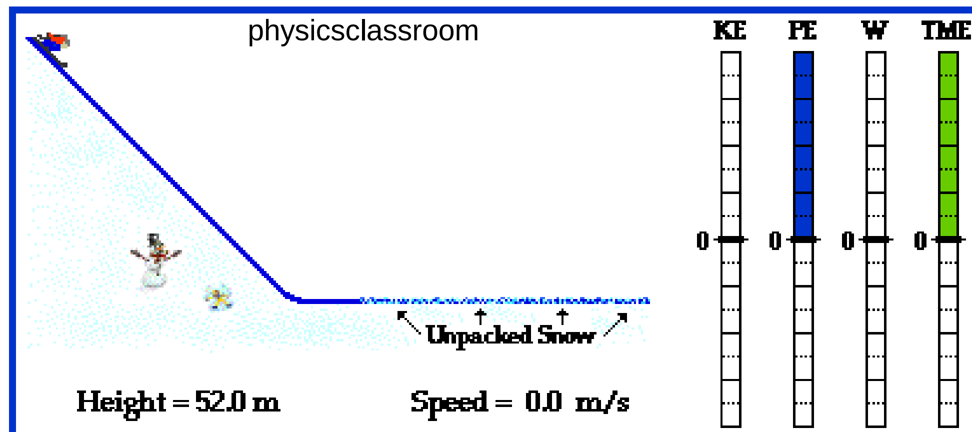
As you know from personal experience,
it takes more work to push an object with a larger frictional force.
Also, when you push an object, you can make it speed-up.

Work: Work done by gravity, *considering* ***kinetic*** *energy*

Consider an object dropped for some height.
How much work has gravity done?

- Initial kinetic energy: KE = (1/2)mv^2 = 0, because $v_i = 0$
- For final kinetic energy, need final velocity:
  - $v_f^2 = v_i^2 + 2a(y_f - y_i) = v_i^2 + 2ah = 2ah$
- $KE_f = \frac{1}{2}mv_f^2 = \frac{1}{2}m(2ah) = mah$
- On Earth, so $a = g$
- Therefore,
  - $W = \Delta KE = KE_f - KE_i$
  - $= mgh - 0$
  - $= mgh$
- So work done by gravity is:
  - $W_{grav} = mgh$

Can convert potential energy into kinetic energy (& back).



- We can ignore kinetics to get work done by gravity!
- This is because work from gravity is work done by moving in a gravitational potential, i.e. work done by changes in **potential energy**.

<u>Work</u>: Work done by gravity, *considering **potential** energy*

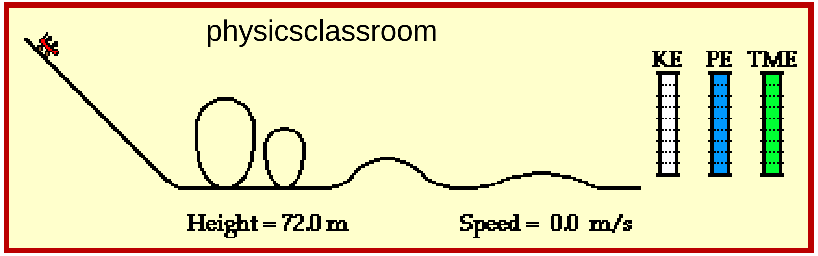
- We established: $W_g = m*g*h$
- But, keep in mind, here "h" = $y_f - y_i$

"h" is positive, because, in our derivation, a = +g, so lower heights are larger y.

- So: $W_g = mgy_i - mgy_f = mgh_i - mgh_f$
- Gravitational potential energy: PE= mgh
- $W_g = PE_i - PE_f = -\Delta PE$

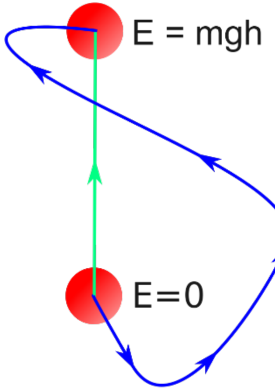
Must choose a reference level for h to calculated Δy and get ΔPE.

- Gravity can be used to store energy:
  - Raise object = convert energy ***into*** PE
  - Lower object = convert energy ***from*** PE



- If we were to lower an object & raise it back to the same spot: $W_g=0$

- The work done by gravity is independent of the path taken!
  - Therefore, it is a "***Conservative Force***".



Book A is raised from the floor to a point 2.0m above the floor.
An identical book (B) is raised from a point 2.0m below the ceiling to the ceiling.
Which book undergoes the greatest increase in gravitational potential energy?

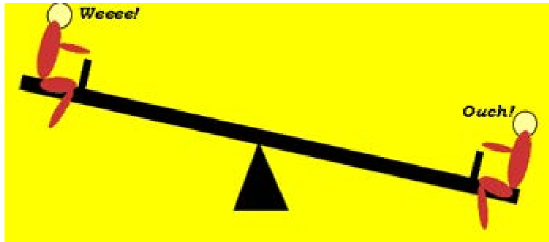
A. Book A
B. Book B
C. Same for both books

- $\Delta PE = mgh_f - mgh_i = mg(\Delta h)$
- For both cases $\Delta h = 2.0m$
- …so same ΔPE

Does it take more energy to walk up one step versus another one higher on the stair case? No!

Kinetic & Potential Energy: The basics

- Kinetic Energy:
  - $KE = (1/2)mv^2$
  - Zero velocity = zero kinetic energy
- Potential Energy:
  - $PE = mgh$
  - Zero at reference level, non-zero above & below
- Can convert from one KE to another:
  - Vibrating vocal cords (KE_1) bump into air molecules, causing them to oscillate (KE_2). Vibrating air molecules (a.k.a. sound) bump into your ear drum, causing it to vibrate (KE_3). Your ear drum causes bones in the ear to vibrate (KE_4), stimulating nerves in the ear, which send electrical impulses to your brain.
- Can convert from one PE to another:
  - Think of people on a teeter-totter.

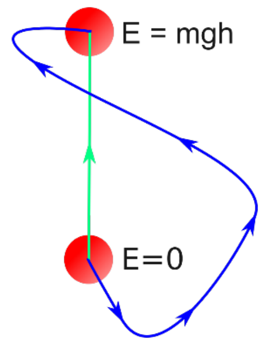


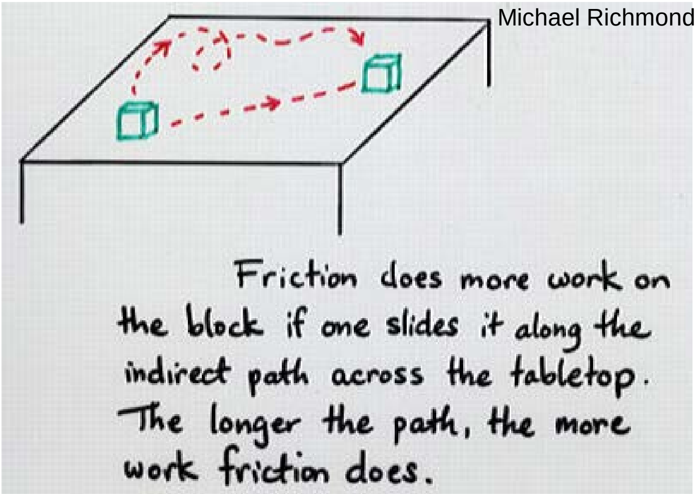
- Can convert from KE to PE & back:
  - On a roller coaster, your initial height is converted to a high speed. Your high speed allows you to climb high hills later on the coaster.

Conservative & Non-conservative Forces

Sec. 7.5

- A **conservative force** is one for which the work depends only on the beginning and ending points of the motion taken, not the actual path.





A **non-conservative force** is one for which the work depends on the path taken.

- **Conservative:** gravity, springs,
  - Conservative force can be used to create Potential Energy (stored energy)
- **Non-conservative:** Friction, air resistance, tension, normal force, engines, etc…
  - Cannot recover work done by non-conservative force as energy

Non-conservative forces & Energy

- Both Conservative & Non-conservative forces can change kinetic energy KE
  - $\Delta KE = W_{net}$
  - $\Delta KE = W_{NC} + W_C$
- Work done by conservative forces can be stored & therefore treated as a change in potential energy PE
  - $W_C = -\Delta PE$
  - So … $\Delta KE = W_{NC} - \Delta PE$
  - $W_{NC} = \Delta KE + \Delta PE$
- Total Mechanical Energy: TME = E = KE +PE
- So, $W_{NC} = \Delta E$
  - $W_{NC} = \Delta E = E_f - E_i$
  - $E_f = E_i + W_{NC}$
- When considering initial & final energy of a system:
  - $E_f = E_i + W_{NC}$
  - $(KE_f + PE_f) = (KE_i + PE_i) + W_{NC}$
  - …***if*** $W_{NC} = 0$, then $(KE_f + PE_f) = (KE_i + PE_i)$

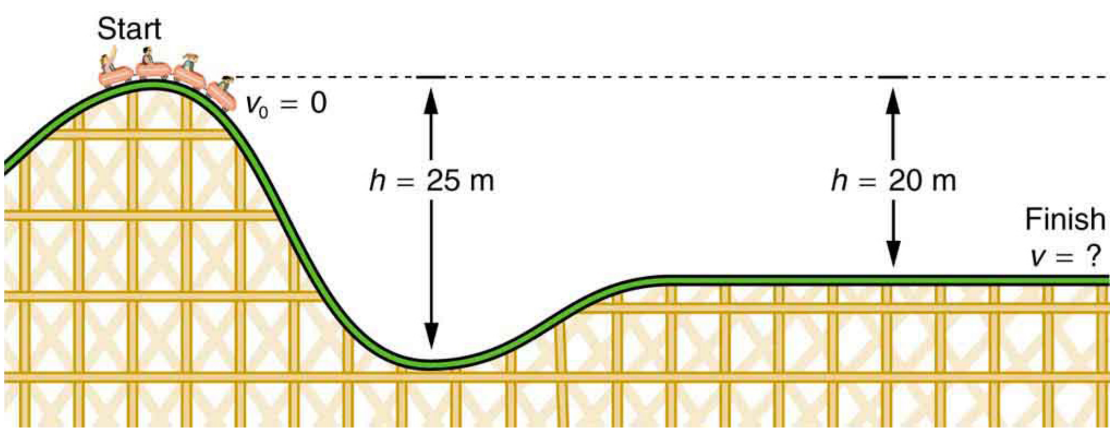
In the absence of non-conservative forces, energy is conserved.

Conservation of Energy

Total energy of a system stays the same ***unless*** there is energy being added or taken away by non-conservative forces.

$$(KE_f + PE_f) = (KE_i + PE_i) + W_{NC}$$

If $W_{NC} = 0$, then the total mechanical energy (TME a.k.a. E) stays the same. Energy may change between types, but the total stays same.



PhET

You have \$100 in your pocket and \$500 in your checking account.
You withdraw some money from the checking account to pay for \$250 worth of books.
You have \$300 left in your checking account.
How much money do you have left in your pocket?

Checking	Pocket	Total Assets
\$500	\$100	? \$600
\$300	? \$50	? \$350

(A) \$0
(B) \$50
(C) \$100
(D) \$150
(E) \$200
(F) \$250

1. Start with total of \$600.
2. Spend \$250 – leaves \$350.
3. If \$300 in Checking, then \$50 in pocket.

Energy accounting is like financial accounting.

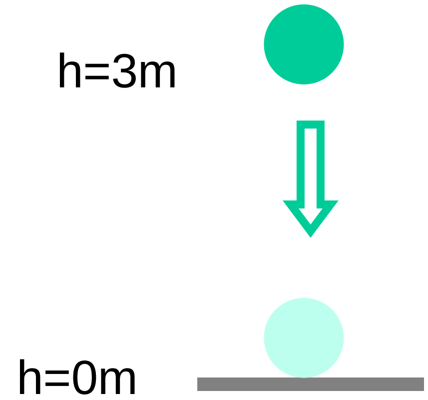
An airplane has 25,000J of KE and a potential energy of 100,000J.
The airplane slowly descends.
During this time drag forces do a total of 5,000J of work on the plane.
The final potential energy is 90,000J.
What is the final KE of the plane?

PE	KE	Total Mechanical Energy
100,000J	25,000J	? 125,000 J
90,000	? 30,000J	? 120,000 J

(A)10,000J
(B) 15,000J
(C) 20,000J
(D) 25,000J
(E) 30,000J
(F) 35,000J

1. Total E = $KE_i + PE_i$ = 25,000J + 100,000J = 125,000J
2. Lose 5000
    1. $E_f = E_i$ - 5000J = 125,000J - 5,000J = 120,000J
3. In the end, 90,000 in form of PE
    1. $E_f = PE_f + KE_f$
    2. KE_f = 120,000J - 90,000J =30,000J

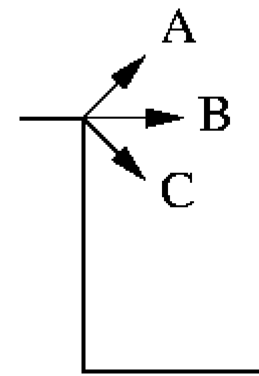
An 0.2kg ball is dropped from a height of 3.0m above the floor. What is the speed of the ball just before it hits the floor? (ignore air resistance)



(A) 3m/s (B) 9.8m/s (C) 5.9m/s (D) 7.7m/s

- Could use free-fall equations…
  …but using energy is easier.
- Know mass, final & initial heights, & initial velocity. Therefore, know:
  - $PE_i = mgh_i = (0.2kg)*(9.8m/s^2)*(3m) = 5.88J$
  - $PE_f = mgh_f = m*g*(0m) = 0J$
  - $KE_i = (1/2)mv_i^2 = (1/2)m(0m/s)^2 = 0J$
- $E_f = E_i + W_{NC}$
  - No non-conservative forces, so $W_{NC} = 0$ …. so, $E_f = E_i$
  - $PE_i + KE_i = PE_f + KE_f$
- $KE_f = 5.88J = (1/2)mv_f^2$
- $v_f = \sqrt{2KE/m} = \sqrt{2(5.88J)/(0.2kg)} = \sqrt{2(5.88kgm^2s^{-2})/(0.2kg)} = 7.7m/s$

3 balls of the same mass are thrown from a cliff, all with a speed of 25m/s.
A is thrown upward at an angle of 45˚.
B is thrown horizontally.
C is thrown downward at an angle of 45˚.
Which one is traveling fastest just before it hits the ground?



(A) A (B) B (C) C **(D) All have the same speed**

1. No non-conservative forces, so $E_f = E_i$
2. $E_i = mgh + (1/2)mv^2$
   1. Same mass & same initial height
   2. “Same speed”; i.e. same v
   3. …So same E_i
3. $E_f = KE_f + PE_f$
   1. $PE_f = mgh = mg*(0m) = 0J$
   2. $E_f = KE_f$
4. $KE_f = (1/2)mv^2 = E_i$, which is the same for all
5. Since m is the same, v_f must therefore be the same

Four identical balls roll off four tracks.
The tracks are of the same height but different shapes, as shown.
For which track is the ball moving the fastest when it leaves the track?

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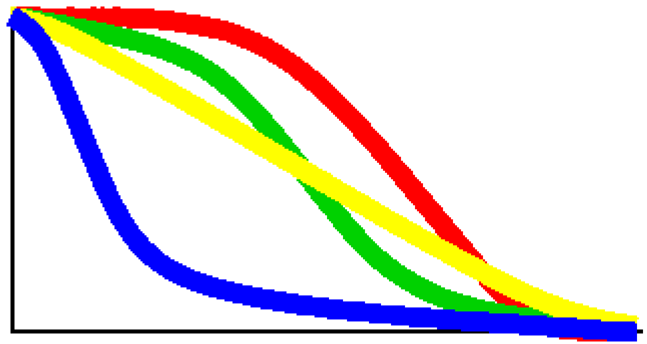
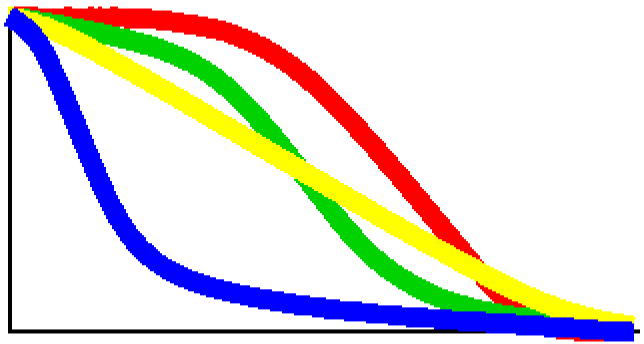


A. Yellow
B. Red
C. Green
D. Blue
E. All the same

1. No non-conservative forces, so $E_f = E_i$
2. $E_i = mgh + (1/2)mv^2$
   1. Same mass, same initial height, all starting from rest (KE_i=0)
   2. So same E_i
3. $E_f = KE_f + PE_f$
   1. $PE_f = mgh = mg*(0m) = 0J$
   2. $E_f = KE_f$
4. $KE_f = (1/2)mv^2 = E_i$, which is the same for all (b/c all leaving at same height)
5. Since m is the same, v_f must therefore be the same

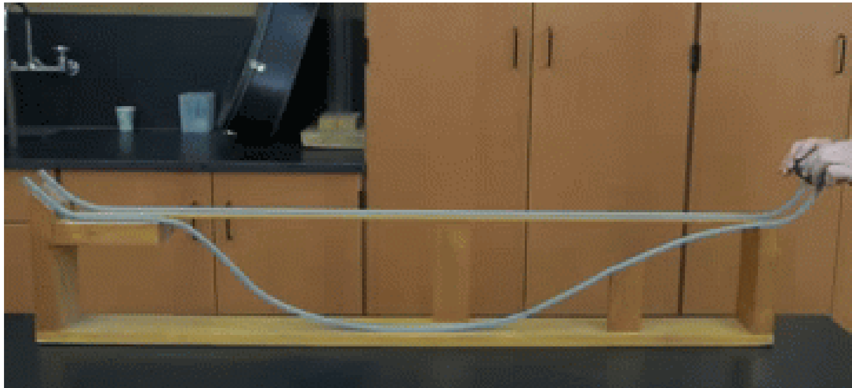
Four identical balls roll off four tracks.
The tracks are of the same height but different shapes, as shown.
For which track does the trip from start to finish take the least time?



A. Yellow
B. Red
C. Green
D. Blue
E. All the same

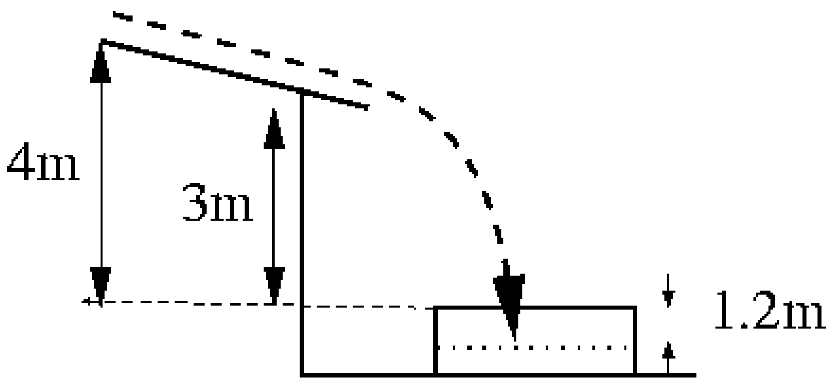
1. A ball on the blue path converts PE to KE very early-on.
2. Increased KE earlier, means increased velocity earlier
3. Increased velocity means less travel time

Energy conservation helps deal with complicated object paths, but we lose time information!



Bruce Yeaney
https://www.youtube.com/watch?v=DCMQRPQS9T4

An 80-kg stunt-person starts at rest and slides down a roof, flies through the air, and lands on a large pad, which compresses 1.2m in order to bring the stunt-person to a stop. Assume it is an icy day and the roof is frictionless. Ignore air resistance. What is the average force on the stunt-person due to the pad?
(Hint: pick the top of the landing pad as the h=0 reference level.)



(A) 3400 N
(B) 3140 N
(C) 4080 N
(D) 0 N
(E) 940 N
(F) 2350 N

$$(KE_f + PE_f) = (KE_i + PE_i) + W_{NC}$$

1. $(KE_F + PE_F) = (KE_0 + PE_0) + W_{NC}$
2. $(0+(-1.2)mg) = (0 + 4mg) + F*d*\cos(180^o)$
3. $-1.2mg = 4mg + F*(1.2)*(-1)$
4. $1.2F = 5.2mg$
5. $F = 3400$ N

	KE	PE	E_{TOT}
Top	0	mg(4m)	4mg
Top of Pad	$\frac{1}{2}mv^2$	0	$\frac{1}{2}mv^2$
Rest	0	mg(-1.2m)	-1.2mg