Introduction to physics, mechanics, project

Physics is the most fundamental science, describing mechanical motion of solids and fluids, thermodynamics, electromagnetism, quantum mechanics, relativity theory, etc.

Question:

What do you want from this physics course?

Your project can be about any topic in physics, which you like or interested in. You may present your project to the audience.

Question:

Explain Bernoulli experiment.

Compare efficiency of truck and trolley.

One egg his stationary egg. Which egg is more likely to crack?

Big foot vs small foot

Small foot is more likely to be more accurate and more precise, give less random error and systematic error because small foot can kick more accurately and precisely with respect to centre of mass of soccer ball.

Because of that, Messi is smaller and better than Ronaldo, who is bigger but, in real life, Ronaldo can kick the ball very accurately and precisely. In this case, physics fails but just a little bit.

Question:

Is big or small foot better for more accurate and precise kick of soccer ball?

Is Ronaldo or Messi better for that?

Base units

There are 7 base units in physics: meter, second, kilogram, ampere, kelvin, mol, candela.

Significant figures are needed to use appropriate precision in numbers, describing measurements.

Use Atlantic rule and Pacific rule to determine number of significant figures.

Question:

How many significant figures are there in your T number?

**Classical mechanics**

Classical mechanics is among the oldest branches of physics,

it is one of the most basic, it describes motion of the objects around us.

**Limits for use of classical mechanics**

Classical mechanics is used for speeds, which are much smaller than speed of light and distances, which are much larger than 1 nano meter and much smaller than the size of our Galaxy, which is measured in light years (beyond this it is dealt with by relativity theory, quantum physics, astrophysics).

Classical mechanics is usually used for macro-objects (from 1 micro-meter to several kilometres) and for speeds between 0 and several speeds of sound).

Question:

Where can classical mechanics be used?

**Material point**

Material point is infinitely small, we neglect its sizes.

It is often possible with high accuracy and precision.

Examples of material points in physics can be bullet,

cannon ball, tennis ball, etc.

if we compare their sizes to much bigger objects,

such as Earth, Galaxy, etc.

If object is big enough then we can often consider it as material point,

located in the centre of mass.

Definitions:

Distance is the total movement of object without regard to direction.

Displacement is distance moved in a particular direction.

Mass is the measure of resistance to change in motion (inertial mass).

Gravitational mass is measure of strength of gravitational force.

Speed is a scalar quantity that is equal to how far the object has moved divided by time taken.

Velocity is a quantity that designates how fast and in what direction a point is moving.

Momentum is product of mass of particle and its velocity.

Angular velocity is rotation rate, showing how fast object rotates.

Angular acceleration is the time rate of change of angular velocity.

Moment of inertia is resistance to angular acceleration. J = I = mR2

Angular momentum is moment of inertial times angular velocity.

Acceleration is the rate of change of the velocity of an object with respect to time.

Time is continued sequence of existence and events that occurs in irreversible succession from the part, through the present, into the future.

Torque is measure of force that can cause an object to rotate about an axis.

Question:

Define distance, displacement, time, speed, velocity, liner acceleration, linear momentum, angular velocity, angular acceleration, angular momentum, moment of inertia, force, torque.

Force

Force changes motion of body.

If physics, by nature, forces can be gravitational, electromagnetic, nuclear weak, nuclear strong.

By way of application, forces can be surface forces (friction) and volume forces (gravity, electromagnetism).

Surface force acts across surface element of body.

Volume force acts on all particles of given body.

Kinematics

To find equations of velocity and acceleration using the equation of displacement, differentiate the equation once to find the velocity, differentiate the equation of displacement twice or equation of velocity once to get the equation of acceleration, differentiate with respect to time t.

Question:

Find velocity and acceleration for one-dimensional motion with the equation x = -k + Lt + Tt2.

k = s mod 10000

T = s mod 100

L = s mod 10

s is your student number.

**Kinematics**

**Acceleration kinematics**

x = x0 + tV0 + 0.5at2

V = V0 + at

V2 = $V\_{0}^{2}$+2a(x – x0)

Question:

Prove that V2 = $V\_{0}^{2}$+2a(x – x0).

Momentum:

Linear momentum:

**p** = m**v** (1)

$p=\sum\_{i=1}^{n}m\_{i}v\_{i}$. (2)

(1) is the expression of linear momentum for one material point.

(2) is the expression of linear momentum for the mechanical system of n material points.

**Collisions**:

We consider one-dimensional motion of material points.

Inelastic collisions or perfectly inelastic collisions:

Two balls (material points) collide without external forces (without friction, etc.) along the straight line (one-dimensional motion), after the inelastic collision both balls move with the same velocity being stick to each other.

Before the collision the masses and the velocities of the balls are m1 and m2, v1 and v2, respectively.

After the collision the balls move together with the same velocity v.

Momentum is conserved: momentum before the collision is equal to momentum after the collision.

m1v1 + m2v2 = (m1 + m2)v (3)

$v=\frac{m\_{1}v\_{1}+ m\_{2}v\_{2}}{m\_{1}+ m\_{2}}$ (4)

Describing the inelastic collision, we assume that the momentum is conserved. The material points stick together after collision and move with the same velocity. We consider one-dimensional motion.

Question:

Calculate the final speed after absolutely inelastic collision of two balls of masses L kg and T kg, moving with velocities s m/s and k m/s respectively.

T = s mod 100

L = s mod 10

s is your student number.

u1 = 1

u2 = 0

m1 = 1

m2 = 1

v = (m1 \* u1 + m2 \* u2) / (m1 + m2)

MsgBox v

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**Elastic collisions or perfectly elastic collisions**:

This is more complex problem because instead of one unknown v there two unknowns V1 and V2.

This time we use the law of conservation of kinetic energy in addition to the law of conservation of momentum.

There two simultaneous equations to solve in this case for V1 and V2.

m1v1 + m2v2 = m1V1 + m2V2 (5)

$\frac{m\_{1}v\_{1}^{2}}{2}+\frac{m\_{2}v\_{2}^{2}}{2}=\frac{m\_{1}V\_{1}^{2}}{2}+\frac{m\_{2}V\_{2}^{2}}{2}$ (6)

These simultaneous equations are quadratic; there will be two solutions for V1 and two solutions for V2.

We must choose the correct solutions based on the physical conditions.

We solve the quadratic simultaneous equations by substitution, expressing V2 through V1 from the first equation and substituting the expression into the second equation.

$V\_{2}=\frac{m\_{1}v\_{1}+m\_{2}v\_{2}-m\_{1}V\_{1}}{m\_{2}}$ (7)

Substituting (7) to (6), we get the single quadratic equation for V1. By solving the single quadratic equation and finding two values of V1, we must decide with of the two answers is the correct physical value for V1.

V2 can be found through V1 using (7).

Conservation of momentum

Momentum is conserved only for absolutely inelastic collision and absolutely elastic collision.

Absolutely elastic collision has 2 equations: conservation of momentum and conservation of kinetic energy

We neglect resistance to motion.

Question:

Solve the elastic collision problem for u1 = k, u2 = k/2, m1 = k, m2 = 2k.

u1 = 1

u2 = -1

m1 = 1

m2 = 1

'

v1 = ((m1 - m2) \* u1 + 2 \* m2 \* u2) / (m1 + m2)

v2 = v1 + u1 - u2

'

MsgBox v1

MsgBox v2

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**Dynamics**

Dynamics studies motion of bodies under the influence of forces.

**Mechanical system**

Mechanical system consists of many material points.

Centre of mass of discrete mechanical system is weighted average.

Centre of mass of continuous mechanical system is weighted average,

expressed through integrals.

**Centre of mass**

Only external force can change location of centre of mass of mechanical system.

Internal force cannot change location of centre of mass of mechanical system.

Equation for centre of mass for 2 material points is weighted average: $C\_{m}=\frac{m\_{1}x\_{1}+m\_{2}x\_{2}}{m\_{1}+m\_{2}}$

The equation for any number of material points is similar, the difference is in the number of terms: 3 terms for 3 points, etc.

Centre of gravity may be different from centre of mass.

Question:

Find the centre of mass of 2 equal masses k meters apart.

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**Internal forces and external forces**

I cannot pull myself out of mud because my force is internal force for the mechanical system.

I can only get out of mud if I use external friction force or get help from other people.

Question:

Can I pull myself out of mud? Why?

**Momentum**

Momentum of material point is mv.

Here m is mass of material point and V is velocity of material point.

**Kinetic energy**

Kinetic energy of material point is mv2/2

Note that derivative of kinetic energy with respect to velocity is equal to momentum.

Question:

Prove that derivative of kinetic energy with respect to velocity is equal to momentum.

**Potential energy** is mgh

m is mass.

g is gravity acceleration.

h is height.

**Laws of Newton**

Laws of Newton describe motion or stationary states of bodies under the influence of forces

First Law of Newton says that there is no acceleration without force, it follows from Second Law of Newton.

Second Law of Newton: F = ma

Third Law of Newton says that action is equal to reaction: F1 = - F2.

**Mass**

Mass is the measure of inertial of body, measure of how much body resists acceleration.

There is also gravitational mass, which shows how much body is attracted by other bodies due to gravitational force.

Question:

What is mass?

**Two-dimensional motion**

Projectile

Projectile is a material point, moving under the influence of gravity in two-dimensions. We solved differential equations of Second Law of Newton, using the initial conditions to determine the integration constants.

Projectile is particular case of motion with constant acceleration a = -g.

g is gravity acceleration.

Projectile is described by Second Law of Newton in 2 dimensions.

We solve ordinary differential equations of second order.

x: Fx = 0, therefore no acceleration along x, there will be constant velocity along x.

y: Fy = -mg = ma, therefore there is constant acceleration along y.

To get the velocity, we must integrate differential equation of Second Law of Newton once.

Velocity of the projectile is:

Vx = V0cosA

Vy = V0sinA – gt

Here we used initial conditions for time t = 0

Vx(0) = V0cosA

Vy(0) = V0sinA

Using the fact that Vy = 0 at maximum height and symmetry of trajectory:

Total time is: 2(V0sinA)/g

Time for maximum height is: (V0sinA)/g

To find distance, we must integrate differential equations of Second Law of Newton twice.

x = x0 + tV0cosA

y = y0 + tV0sinA – 0.5gt2

Here we used initial conditions for time t = 0

x(0) = x0

y(0) = y0

y as a function of x:

y = xtanA – (1 + (tanA)2)gx2/(2(V0)2)

tanA = sinA/cosA

You can find minimum initial velocity and corresponding angle of release to hit any point in space.

Question:

Find Maximum x, Maximum y; find x and y at time = T seconds, for angle of release A = T degrees, initial velocity V0 = T meters per second, x0 = y0 = 0 meters for projectile.

T = s mod 100

s is your student number.

s = 19107016

T = s Mod 100

v0 = T

g = 10

Pi = 4 \* Atn(1)

A = T \* Pi / 180

x0 = 0

y0 = 0

x = x0 + T \* v0 \* Cos(A)

y = y0 + T \* v0 \* Sin(A) - g \* T / 2

MsgBox x

MsgBox y

xmax = v0 ^ 2 \* Sin(2 \* A) / g

ymax = v0 ^ 2 \* (Sin(A)) ^ 2 / (2 \* g)

MsgBox xmax

MsgBox ymax

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Question:

Find the velocity at time = T seconds, for angle of release A = T degrees, initial velocity V0 = T meters per second, x0 = y0 = 0 meters for projectile.

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Question:

Calculate total time of the motion and time for maximum height for angle of release A = T degrees, initial velocity V0 = T meters per second, x0 = y0 = 0 meters for projectile.

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Question:

Find minimum velocity and corresponding angle of release of projectile to hit the point (s, T).

$$x=tvcosA$$

$$y=tvsinA-\frac{gt^{2}}{2}$$

$$y=xTanA-\frac{gx^{2}}{2v^{2}}\left(1+\left(TanA\right)^{2}\right)$$

$$v^{2}=\frac{\left(1+\left(TanA\right)^{2}\right)gx^{2}}{2\left(y-xTanA\right)}$$

$$TanA=T$$

$$v^{2}=\frac{\left(1+T^{2}\right)gx^{2}}{2\left(y-xT\right)}$$

$$0=\frac{∂\left(v^{2}\right)}{∂T}=\frac{gx^{2}}{2}\left[\frac{\left(1+2T\right)\left(y-xT\right)+\left(1+T^{2}\right)x}{\left(y-xT\right)^{2}}\right]=0$$

$$xT^{2}+\left(x-2y\right)T-\left(x+y\right)=0$$

$$T\_{1,2}=\frac{2y-x\mp \sqrt{\left(x-2y\right)^{2}+4x\left(x+y\right)}}{2x}$$

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' minimum velocity for projectile

x = 11

y = 2.5

'

g = 10

'

T1 = (2 \* y - x + Sqr((x - 2 \* y) ^ 2 + 4 \* x \* (x + y))) / (2 \* x)

T2 = (2 \* y - x - Sqr((x - 2 \* y) ^ 2 + 4 \* x \* (x + y))) / (2 \* x)

'MsgBox T1

'MsgBox T2

'

v1 = Sqr(g \* x ^ 2 \* (1 + T1 ^ 2) / (2 \* (x \* T1 - y)))

MsgBox v1

'v2 = Sqr(g \* x ^ 2 \* (1 + T2 ^ 2) / (2 \* (x \* T2 - y)))

'MsgBox v2

MsgBox Atn(T1) \* 180 / (4 \* Atn(1))

'MsgBox Atn(T2) \* 180 / (4 \* Atn(1))

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Question:

Check correctness of minimum velocity calculation by using x = 0.000000001 and y = 20.

Question:

Calculate minimum velocity for tanA = y/x +1/s

s = 20000000

x = 1

y = 1

g = 10

T1 = 1 / s + y / x

v1 = Sqr(g \* x ^ 2 \* (1 + T1 ^ 2) / (2 \* (x \* T1 - y)))

MsgBox v1

Question:

Find all projectile solutions for V0 = V0mimimum + 1/T.

$$x=tvCosA$$

$$y=tvSinA-\frac{gt^{2}}{2}$$

$$y=xTanA-\frac{gx^{2}}{2v^{2}}\left(1+\left(TanA\right)^{2}\right)$$

$$TanA=T$$

Quadratic equation for T:

$$\frac{gx^{2}}{2V^{2}}T^{2}-xT+y+\frac{gx^{2}}{2V^{2}}=0$$

$$T\_{1}=\frac{x+\sqrt{x^{2}-4\frac{gx^{2}}{2V^{2}}\left(y+\frac{gx^{2}}{2V^{2}}\right)}}{gx^{2}}V^{2}$$

$$T\_{2}=\frac{x-\sqrt{x^{2}-4\frac{gx^{2}}{2V^{2}}\left(y+\frac{gx^{2}}{2V^{2}}\right)}}{gx^{2}}V^{2}$$

Here V = V0.

s = 22000005

T = s Mod 100

x = 1

y = 1

g = 10

T1 = (2 \* y - x + Sqr((x - 2 \* y) ^ 2 + 4 \* x \* (x + y))) / (2 \* x)

T2 = (2 \* y - x - Sqr((x - 2 \* y) ^ 2 + 4 \* x \* (x + y))) / (2 \* x)

v1 = Sqr(g \* x ^ 2 \* (1 + T1 ^ 2) / (2 \* (x \* T1 - y)))

'v2 = Sqr(g \* x ^ 2 \* (1 + T2 ^ 2) / (2 \* (x \* T2 - y)))

v = v1 + 1 / T

T1 = v \* v \* (x + Sqr(x \* x - 4 \* g \* x \* x \* (y + g \* x \* x / (2 \* v \* v)) / (2 \* v \* v))) / (g \* x \* x)

T2 = v \* v \* (x - Sqr(x \* x - 4 \* g \* x \* x \* (y + g \* x \* x / (2 \* v \* v)) / (2 \* v \* v))) / (g \* x \* x)

MsgBox Atn(T1) \* 180 / (4 \* Atn(1))

MsgBox Atn(T2) \* 180 / (4 \* Atn(1))

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To hit the target as quickly as possible, we need to calculate minimum velocity, provide maximum initial velocity, which must be bigger than minimum velocity, chose the smallest angle of release for the maximum initial velocity.

Question:

How can I hit a target as quickly as possible, using projectile?

Question:

Prove that for the projectile

$$D\_{MAX}=x\_{MAX}=\frac{V\_{0}^{2}\sin(\left(2A\right))}{g}$$

$$H\_{MAX}=y\_{MAX}=\frac{V\_{0}^{2}\left(\sin(A)\right)^{2}}{2g}$$

$$V\_{y}=V\_{0}\sin(A)-gt$$

$$V\_{y}=0$$

$$t\_{H}=\frac{V\_{0}\sin(A)}{g}$$

$$t\_{D}=2t\_{H}$$

$$x\_{MAX}=D\_{MAX}=t\_{D}V\_{0}\cos(A)$$

$$y\_{MAX}=H\_{MAX}=t\_{D}V\_{0}\sin(A)-\frac{gt\_{D}^{2}}{2}$$

Diffusion

Substance S diffuses in time in one dimension x.

$\frac{∂S}{∂t}=D\frac{∂^{2}S}{∂x^{2}}$ (equation)

$S\left(\infty ,t\right)=0$ (boundary condition)

$S\left(x,t\right)=\frac{e^{-\frac{x^{2}}{4Dt}}}{\sqrt{4πDt}}$ (solution)