**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.

**One dimensional motion**

**Kinematics**

Momentum:

Linear momentum:

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

. (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)

 (4)

**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)

 (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.

 (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

http://physics16.weebly.com/uploads/5/9/8/5/59854633/linear2elastic4collision.txt

**Acceleration kinematics**

x = x0 + tV0 + 0.5at2

V = V0 + at

V2 = +2a(x – x0)

Question:

Prove that V2 = +2a(x – x0).

**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:

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.

https://physics15.weebly.com/uploads/3/0/2/7/30272185/centerofmass23sept.txt

**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 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 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.

https://physics15.weebly.com/uploads/3/0/2/7/30272185/velocityofprojectile23sept.txt

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.

https://physics15.weebly.com/uploads/3/0/2/7/30272185/timeofprojectile23sept.txt

**One dimensional motion**

**Truck and trolley**

Torque is applied to wheels of truck, which in more efficient than trolley, which is pushed or pulled.

Question:

Compare efficiency of truck and trolley.

Use what we discussed in our class about pulling trolley and rotating wheels of truck.

**Collided eggs**

Your own speed is the most dangerous for you.

Question:

Is moving or stationary egg more likely to crack after the collision?

**Volume**:

Question:

Air purifier purifies 5 cubic meters of air. How many such air purifiers are needed for a room 5×5×10meters?

https://physics15.weebly.com/uploads/3/0/2/7/30272185/volumeforairpurifier23sept.txt

**One dimensional motion**

**Pulley problem**



Pulley problem is solved by projecting all forces to the cord.

Is there are two non-zero different masses, acceleration is not g and not -g, then there will be acceleration a of the masses and tension in the cord.

We neglect the resistance. We assume cord to be massless.

Tension is internal force.

Difference in weights is external force.

If the masses are the same, then there will be no acceleration but there will be tension.

If both masses are zero, then there will be no acceleration and no tension.

If one mass is zero, then there will be acceleration but no tension.

If acceleration is g, then there will be no tension (free fall).

We choose coordinate axis down, along the motion of bigger mass.

Second Law of Newton for two masses: Mg – mg = (M+m)a

T is tension in rope. T is internal force, which can break the rope.

Using free-body diagram for mass M, we will get: Mg – T = Ma

T = M(g - a)

Using free-body diagram for mass m, we will get: T – mg = ma

T = m(g + a)

Question:

Find the acceleration of a simple pulley and tension in the rope for two masses: L kg and T kg.

n = 15108097

k = n Mod 10000

t = n Mod 100

'

g = 10

'

m1 = t \* k / n

m2 = 2 \* k

'

m1 = 1 / k

m2 = 2 \* k

'

a = (m2 - m1) \* g / (m1 + m2)

tt = m1 \* (g + a)

tt = m2 \* (g - a)

'

MsgBox a

MsgBox tt

http://physics16.weebly.com/uploads/5/9/8/5/59854633/problem4pulleys.txt

youtube.com/watch?v=kvCnjVSpuv0

**Friction**

Friction force is resistance to motion.

We often consider sliding friction, for which friction force F = μN.

μ is coefficient of friction.

N is normal reaction.

Question:

Calculate friction force F = μN. μ = 1/T. N = k.

https://en.wikipedia.org/wiki/Friction

https://physics15.weebly.com/uploads/3/0/2/7/30272185/frictionforce23sept.txt

**mv = Ft**

mv = Ft is simplified mechanical equation, which says that change in momentum is equal to impulse of force.

This equation is a particular case of the equation , d(mv) = Fdt,

Question:

A dust particle with mass of 0.00001kg and speed of 5 m/s is subjected to a force of 0.00001N of the filter. How much time will it take to stop the particle?

Use the equations mv = Ft and t = mv/F

https://physics15.weebly.com/uploads/3/0/2/7/30272185/airpurifierproblem23sept.txt

Question:

Biker of mass T kg starts moving from rest. Friction coefficient μ = 1/T. What is the maximum velocity after T seconds?

Use the equations mv = Ft and v = Ft/m

https://physics15.weebly.com/uploads/3/0/2/7/30272185/bikerfrictionmaxspeed23sept.txt

**Rotational motion**

Rotational motion is possible for systems of material points or solids.

Rotation of satellite around planet is often considered as rotation one material point around the other.

Not only satellite is substituted by its centre of mass, but also planet is substituted by its centre of mass.

Period = 1/frequency

Liner acceleration for rotational motion is a = = Rω2

ω is angular velocity, ω = A/t

A is Angle.

t is time.

Linear velocity of rotational motion is: V = Rω.

Question:

Find linear accretion due to rotation for a person on planet with period of rotation of 24 hours and radius s millimetres.

https://physics15.weebly.com/uploads/3/0/2/7/30272185/rotationallinearacceleration23sept.txt

**Breaking rope during rotation of the mass**

If the mass rotates on rope and rope breaks, then the mass will move along the tangent to the circumference of rotation at the point of breaking the rope because there is no force (First Law of Newton), which means that velocity must be the same and velocity during rotational motion is along tangent line to circumference of rotation.

Question:

If the mass rotates on rope and rope breaks, what will be velocity of the mass?

**Rotation vs translation**

Angle A for rotation, distance D for translation

Angular velocity ω for rotation, liner velocity V for translation

Moment of inertia J for rotation, mass m for translation

Angular momentum Jω for rotation, liner momentum mV for translation

Kinetic energy for rotation 0.5Jω2, kinetic energy for translation 0.5mV2

Torque M for rotation, force F for translation

Translation is rotation with infinitely far centre of rotation.

Vectors of angular velocity, angular acceleration, torque are perpendicular to the plain in which there is rotation.

Question:

Compare rotation and translation.

**Energy, work and power**

Energy is the ability to do work.

Work is not always W = DF but sometimes dot-product W = DF or curvilinear integral W =

Power is not always P = W/t but sometimes P =

P = FV

W is work

D is distance

F is force

P is power

t is time

V is velocity

Question:

Explain energy, work and power.

**Conservation laws**

Energy is conserved if no work is done by external forces, all work is done by internal forces.

Energy is conserved when force is derivative of some function, for example, for gravity force

Momentum is conserved when there are no external forces.

Conservation laws are the result of symmetry of space and time.

Question:

Explain conservation laws.

**Gravity force of Newton**

Gravity force of Newton is expressed by equation similar to Law of Colomb

F = G\*m1\*m2/R2

G is gravity constant

m1 and m2 are masses of bodies between which this force is.

R is the distance between centres of masses of the bodies.

Question:

Calculate the difference in weight on the pole and on the equator of the Earth. Take the difference in the distance from the centre of the Earth as 21km.

https://physics15.weebly.com/uploads/3/0/2/7/30272185/differenceingravityforceduetodistance23sept.txt

**Escape velocity, orbital velocity and gravity acceleration**

Escape velocity is velocity of a body falling on a planet from the infinity.

Escape velocity can be found from equation of energy conservation mgh = 0.5m

Orbital velocity is such velocity of projectile for which it will never fall on planet and will become its satellite.

Orbital velocity is found from equation of g = centripetal acceleration: g = /R.

Gravity acceleration can be found, using mass of planet M and its radius R.

We use law of gravity of Newton: F = Gm1m2/R2.

F is gravitational force of Newton.

G is gravitational constant of Newton.

m1 is mass of first body.

m2 is mass of second body.

R is distance between centres of masses of bodies.

Question:

Find gravity acceleration g, orbital velocity Vo and escape velocity Ve for planet with mass s billion tons and radius s millimetres.

s = 17108073

GG = 6.6740831 \* 10 ^ (-11)

M = 10 ^ 12 \* s

R = s / 1000

g = GG \* M / R ^ 2

MsgBox g

Vo = Sqr(g \* R)

MsgBox Vo

Ve = Sqr(2 \* g \* R)

MsgBox Ve

https://physics18.weebly.com/uploads/5/9/8/5/59854633/g1orbital1velocity1escape1velocity13oct2017.txt

**Work-energy theorem**

Change in kinetic energy of mechanical system is equal to work of all external forces and all internal forces.

This theorem solves almost all problems of classical mechanics.

We can illustrate this theorem using V2 = +2a(x – x0) but we can also use this theorem for any number of dimensions.

**Solid mechanics**

Solid mechanics considers motion of rigid bodies (they cannot be deformed).

For rigid body can be subjected to torque M = DF or, for more general case, using cross-product ×,

**M** = **D×F**.

D is the distance to pivot from the direction of force.

F is force.

M is torque.

It is not possible to apply torque to material point where distance = 0.

Solid has moments of inertia with respect to different axes of rotation.

For solids there is rotational equivalent to Second Law of Newton: **M** = J**ε**

J is tensor of moments of inertia.

ε is angular acceleration.

Bold letters mean vectors.

Sliding vector of force must be directed only along one straight line, otherwise, parallel force will cause additional torque.

Free vectors of torque, velocity, angular velocity, momentum, angular momentum can be applied along any parallel straight line.

**Weight**

Weight is the force that object exerts on ground due to gravitational attraction to Earth or another similar object.

weight = mg

Question:

What is your weight?

https://physics15.weebly.com/uploads/3/0/2/7/30272185/weightonearththroughmass23sept.txt

**Free-body diagram**

Free-body diagram shows all forces, which are acting on a body.

Question:

Explain free-body diagram.

**Inclined plane**



Inclined plane problem requires adding up all forces as vectors, finding the resulting force.

It includes weight, normal reaction and friction force.

For no friction:

sinAmg = ma

sinAg = a

For static friction:

F ≤ Nµstatic

For sliding friction:

µ < µstatic

µ is sliding friction coefficient.

We use free-body diagram, identifying all forces acting on mass.

x: sinAmg – µN = ma

y: N – cosAmg = 0

N = cosAmg

sinAmg – µ cosAmg = ma

(sinA – µ cosA)g = a

Question:

Find acceleration of a mass at the inclined plane with

A = T degrees and the friction coefficient μ = 1/T.

s = 19107012

T = s Mod 100

Angle = 4 \* Atn(1) \* T / 180

g = 10

mu = 1 / T

acceleration = g \* (Sin(Angle) - mu \* Cos(Angle))

MsgBox acceleration

youtube.com/watch?v=8xOU25PWx8M

https://physics15.weebly.com/uploads/3/0/2/7/30272185/sept23rampinclinedplane.txt

https://physics16.weebly.com/uploads/5/9/8/5/59854633/ramp4inclined4plane2019oct.txt

http://physics16.weebly.com/uploads/5/9/8/5/59854633/inclined4plane.txt

**Centre of gravity** is the centre of parallel forces.

Centre of gravity is not always the same as centre of mass.

**Statics**

**Blocks stacking problem**



Blocks stacking problem finds locations of blocs to make maximum hangover, which follows harmonic series 1/n, which diverges, which means that hangover can be infinitely big.

We use equations of static equilibrium to solve the problem.

This is logistical problem for computer programmers to solve.

Question:

Find the hangover for the s blocks in the blocks stacking problem.

http://physics16.weebly.com/uploads/5/9/8/5/59854633/hangover.txt

youtube.com/watch?v=Gaua\_V9Fse4

**Angular acceleration, torque, force**

Question:

Find F = ma, M = Jε, for m = a = J = ε = T.

https://physics15.weebly.com/uploads/3/0/2/7/30272185/forceandmomentofforce23sept.txt

**Spring force** F = -kx

k is property of spring

x is displacement

**Pendulum**

Pendulum is used for many useful things: counting time, monitoring rotation of Earth, etc.

**Oscillation**

Oscillation is periodic motion.

We solve ordinary differential equation to describe oscillation.

We can describe oscillation of mass, attached to spring.

**Resonance** is when amplitude of oscillation becomes infinite because frequencies of external force and natural frequency of the oscillator are the same.

Question:

Give period of spring oscillator . m = m35. k = m10000.

https://physics16.weebly.com/uploads/5/9/8/5/59854633/spring4oscillator2019nov.txt

Question:

Find period of pendulum . L = m10.

https://physics16.weebly.com/uploads/5/9/8/5/59854633/pendulum4period2019nov.txt

Question:

Find the displacement of a harmonic oscillator after s seconds with amplitude k, frequency k and initial phase k/2.

http://physics16.weebly.com/uploads/5/9/8/5/59854633/harmonic4oscillator.txt

Question:

Solve oscillation problem y'' + yT2 = 0.

https://www.wolframalpha.com/input/?i=y%27%27+%2B+16y+%3D+0

Question:

Ty'' + Ly = sin(ωx)

Find resonant ω.

https://physics16.weebly.com/uploads/5/9/8/5/59854633/resonant4frequency2019nov.txt

Question:

Forced vibration with damping:

Ty'' + my' + Ly = sin(Tx)

Is there resonance?

m = m35

L = m10

http://www.wolframalpha.com/widgets/view.jsp?id=e602dcdecb1843943960b5197efd3f2a

**Waves**

Wave is spread of oscillation in space.

Waves have properties of interference and diffraction.

Interference is when waves of the seme frequency interact creating picture of maxima and minima.

Diffraction is when wave goes around the obstacle.

Question:

Solve the string oscillatory equation for v = T, frequency = L = m10, Amplitude = T.

Find the displacement after s seconds at m meters.

https://physics18.weebly.com/uploads/5/9/8/5/59854633/string1wave1oscillation22oct2017.txt

**Interference**:

sin(ω(t – x/v)) + sin(L + ω(t – x/v)) = 2sin(0.5L + ω(t – x/v)cos(0.5L)

Question:

Give interference equation for sin(ω(t – x/v)) and sin(L + ω(t – x/v)). L = m10. ω = T. t = T.

https://physics16.weebly.com/uploads/5/9/8/5/59854633/interference2019nov.txt

**Mathematics for physics**

Angular calculus

Degrees and radians

Trigonometric calculus

Derivatives and integrals of sin, cos, tan and other trigonometric functions

Differential equations

Functions of many variables

Vector calculus

Add, subtract, multiply vectors (dot-product, cross-product)

Tensor calculus

Multiply tensor by vector

Details for mathematics in physics are here:

calculus12s.weebly.com

calculus17.weebly.com

calculus1only.weebly.com

calculus2only.weebly.com

discrete4math.weebly.com

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