G02_HW09

Group 02
HW 09
2019/11/19

ID	Name	Your works	Times you spend	Self score	TA
108202529	葉揚昀	Photodiode	11hr	9	
108202009	田家瑋	Photoresistor & Photomultiplier	9hr	6	
108202016	張家菖	Design coupled oscillator	10hr	9	

Photodiode

1. Definition:

A photodiode is a p-n junction or pin semiconductor device that consumes light energy to generate electric current. It is sometimes referred as photo-detector, photo-sensor, or light detector.

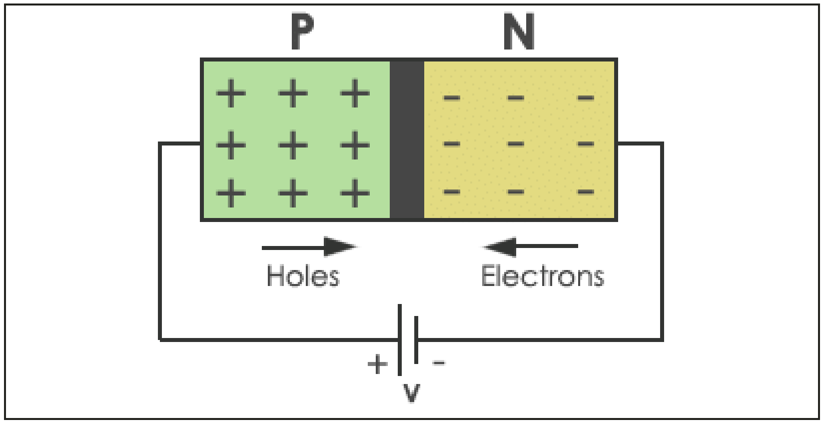


Fig.1 A p–n junction is a boundary or interface between two types of semiconductor materials, p-type and n-type, inside a single crystal of semiconductor.
source: https://reurl.cc/Vam1LQ

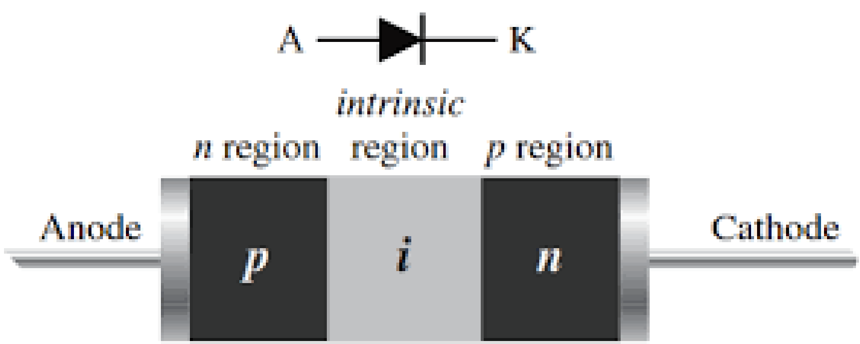


Fig.2 A PIN diode is a diode with a wide, undoped intrinsic semiconductor region between a p-type semiconductor and an n-type semiconductor region.
source: https://reurl.cc/qDKN0E

Photodiode

2. Operation principle:

(1) Construction of p-n junction diode:

Terminal
- P: Anode terminal (+)
- N: Cathode terminal (-)

Carriers
- P: Majority carriers: holes, Minority carries: free electrons
- N: Majority carriers: free electrons, Minority carries: holes

Immobile ions
- P: 3A negative ions (eg: Boron atom) (original: Trivalent)
- N: 5A positive ions (eg: Phosphorus atom) (original: Pentavalent)

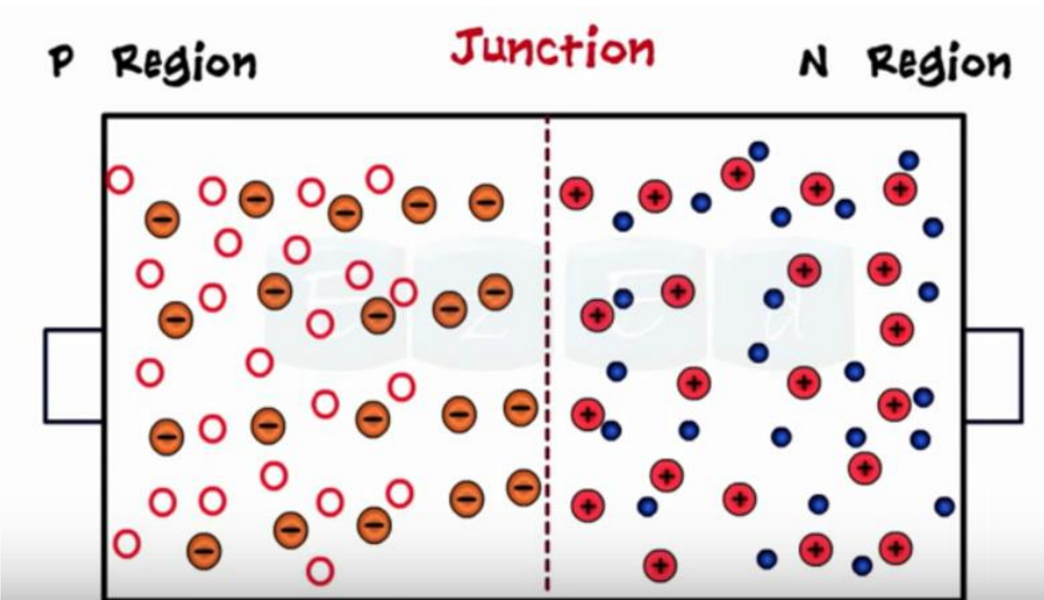


Fig.3 The construction of p-n junction diode
source:
https://www.youtube.com/watch?v=n0SiQIaitHk&t=503s

Photodiode

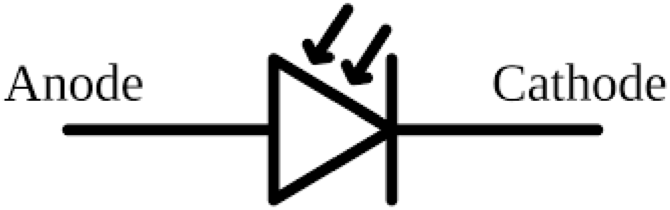


Fig.4 The electronic symbol of photodiode (the arrow tracking the diode represent light or photons) source: https://reurl.cc/A1bOEQ

(2) Diffusion & Depletion region

The electrons from the N side get attracted towards the holes of the P side. These electrons cross over the junction recombine with holes and cease to be free carriers. This process is called diffusion.

Diffusion remains restricted near the junction. Only as free electrons and holes get depleted from the region near the junction. This region is called depletion region.

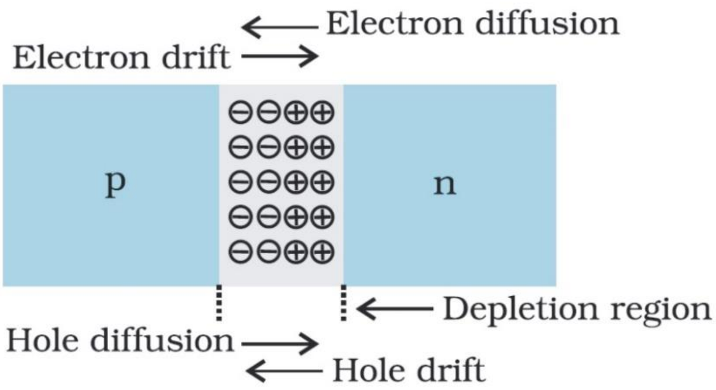


Fig.5 The process of diffusion & depletion region source: https://www.semiconductorforu.com/pn-junction-formed/

Photodiode

(3) Junction potential

After p-n junction form a depletion region, the depletion region contains only negative ions on P side and positive ions on n side of the junction. These charged ions develop an electric field in the depletion region known as junction potential.

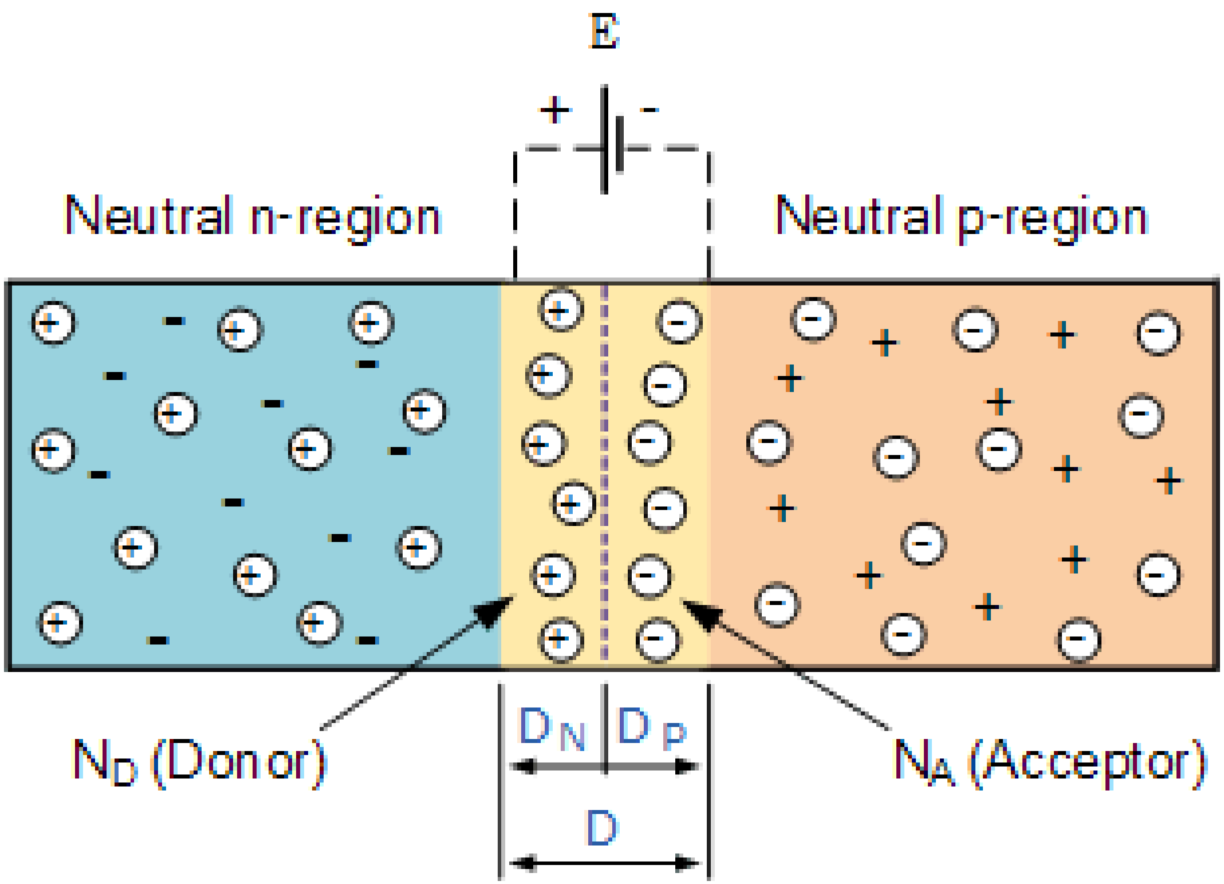


Fig.6 The depletion region cause junction potential.
source: https://reurl.cc/0za6eK

Photodiode

(4) Incident light (contain photons)

When a photon of sufficient energy strikes the diode, it creates an electron–hole pair. This mechanism is also known as the inner photoelectric effect. Thus holes move toward the anode, and electrons toward the cathode, and a photocurrent is produced.

The total current through the photodiode is the sum of the dark current (current that is generated in the absence of light) and the photocurrent.

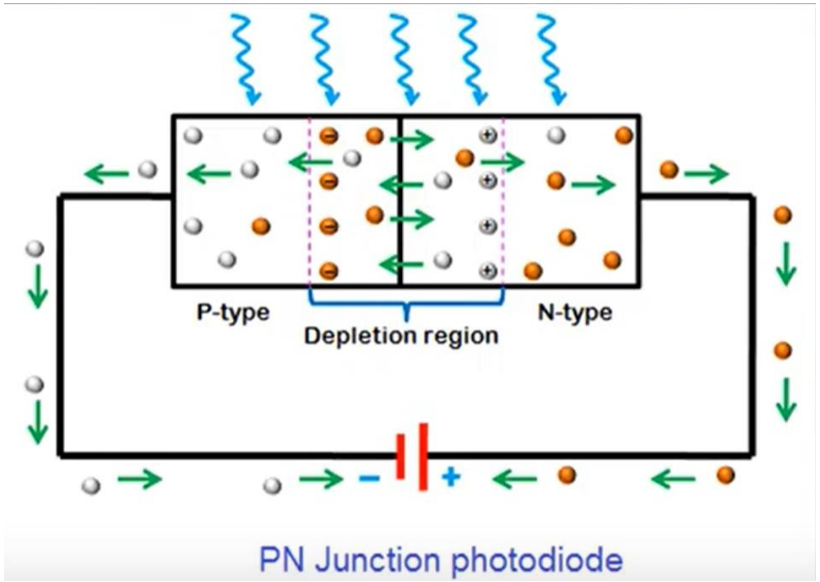


Fig.7 In photodiodes, we use light or photons as the external energy to generate charge carriers.
source: https://www.youtube.com/watch?v=8k9UIlwo7W4

Photodiode

3. Dark current

Dark current is the relatively small electric current that flows through photosensitive devices such as a photomultiplier tube, photodiode, or charge-coupled device even when no photons are entering the device.

It is referred to as reverse bias leakage current in non-optical devices and is present in all diodes.

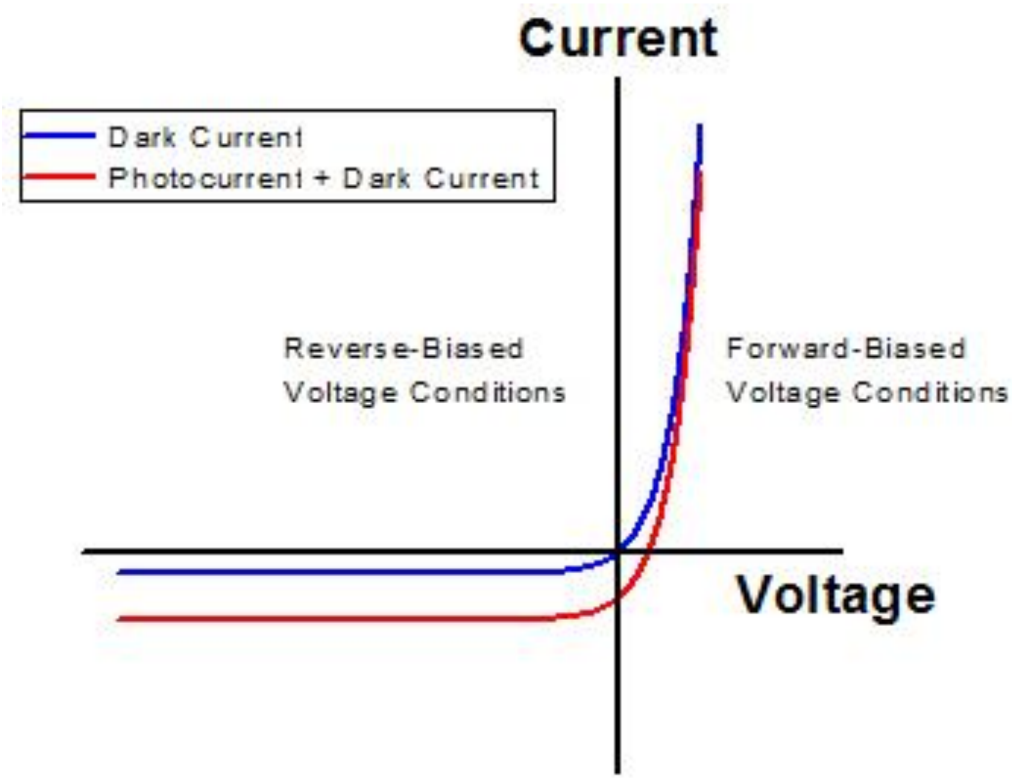


Fig.8 Dark current & Total current (Dark current + photocurrent)
source: https://reurl.cc/drq7vz

Photodiode

Complement: Bias

(1) Forward bias:

In forward bias, the p-type is connected with the positive terminal and the n-type is connected with the negative terminal.

(2) Reserve bias:

Connecting the p-type region to the negative terminal of the battery and the n-type region to the positive terminal corresponds to reverse bias.

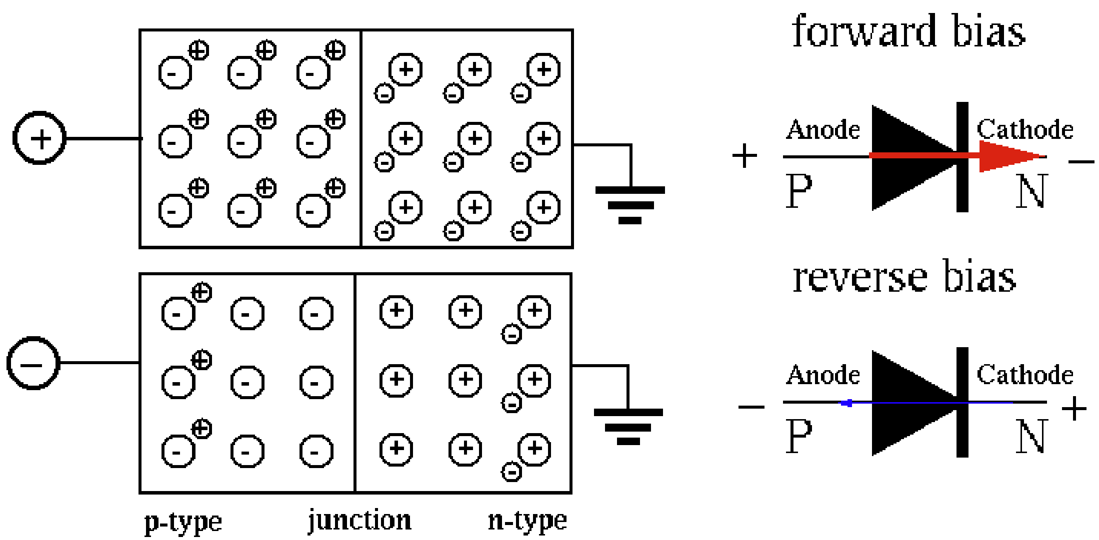


Fig.9 Forward bias & Reserve bias
source: http://fourier.eng.hmc.edu/e84/lectures/ch4/node2.html

Photodiode

4. Main parameter

(1) Size of depletion region

1. The potential difference across p-n junction can be shown as:

$$\Delta V = \frac{C_A C_D}{C_A + C_D} \frac{q}{2\varepsilon} (d_p + d_n)^2 \tag{1}$$

2. Use equation (1) we get:

$$d = d_p + d_n = \sqrt{\frac{2\varepsilon}{q} \frac{C_A + C_D}{C_A C_D} \Delta V} \tag{2}$$

3. Due to $\Delta V = \Delta V_0 + \Delta V_{ext}$,express ΔV_0:

$$\Delta V_0 = \frac{kT}{q} ln\left(\frac{C_A C_D}{P_0 N_0}\right) \tag{3}$$

Photodiode

(2) Quantum efficiency & Responsivity

1. A photodiode's capability to convert light to electrons, expressed as a percentage, is Q.E..

$$Q.E. = \eta = \frac{r_e}{r_p} = \frac{electrons\ (holes)\ collected/sec}{incident\ photons/sec} \tag{4}$$

2. Calculate I_p & P :

$$\left[\begin{array}{l} r_p = \dfrac{p}{hf}, r_e = \eta r_p = \dfrac{\eta p}{hf} \rightarrow I_p = e r_e = e\dfrac{\eta p}{hf} \\ \\ P = r_p hf \end{array}\right. \tag{5}$$

3. Combine equation (5), and represent responsivity R_λ:

$$R_\lambda = \frac{I_p}{P}\ \text{(A/w)} = \frac{\frac{e\eta p}{hf}}{r_p hf} = \frac{e\eta}{hf} = \frac{e\eta\lambda}{hc} = \frac{\eta\lambda}{1.24}\ \text{(A/w)} \tag{6}$$

Photodiode

(3) Noise-equivalent power (NEP)

1. NEP is a measure of the sensitivity of a photodetector or detector system.

$$\mathrm{NEP} = \frac{N_0 \left(\frac{A}{\sqrt{Hz}}\right) or \left(\frac{V}{\sqrt{Hz}}\right)}{R_\lambda \left(\frac{A}{W}\right) or \left(\frac{V}{W}\right)} \left(\frac{W}{\sqrt{Hz}}\right) \tag{7}$$

2. Calculate N_0 (Noise spectral density):

$$N_0 = \begin{cases} r_p = \frac{N}{B} = \frac{total\ noise\ power}{bandwidth} \\ kT, k = Boltzmann's\ constant \end{cases} \tag{8}$$

3. Meaning of NEP

- NEP $\downarrow$ $\rightarrow$ sensitivity of a photodetector $\uparrow$
- NEP $\uparrow$ $\rightarrow$ sensitivity of a photodetector $\downarrow$

Photodiode

(4) Some example of photodiodes with different parameters.

Si Photodiodes - VIS Wavelengths

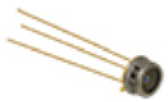
Click Image for Details				
Item #	FDS010	FD11A	FDS10X10	FDS100
Key Feature	High Speed, UV Grade Fused Silica Window to Provide Sensitivity Down to 200 nm	Lowest Dark Current in TO-18 Can with a Window	Low Dark Current in 10 mm x 10 mm Ceramic Package	High Speed, Largest Sensor in a TO-5 Can
Info				
Wavelength Range	200 - 1100 nm[a]	320 - 1100 nm	340 - 1100 nm	350 - 1100 nm
Active Area	0.8 mm^2 (Ø1.0 mm)	1.21 mm^2 (1.1 mm x 1.1 mm)	100 mm^2 (10 mm x 10 mm)	13 mm^2 (3.6 mm x 3.6 mm)
Rise/Fall Time[b]	1 ns / 1 ns @ 830 nm, 10 V	400 nsc[c,d] @ 650 nm, 0 V	150 ns / 150 ns[d] @ 5 V	10 ns / 10 ns[d] @ 632 nm, 20 V
NEP (W/Hz$^{1/2}$)	5.0 x 10^{-14} @ 830 nm, 10 V	6.8 x 10^{-16} @ 960 nm, 0 V	1.50 x 10^{-14} @ 960 nm	1.2 x 10^{-14} @ 900 nm, 20 V
Dark Current	0.3 nA (Typ.) @ 10 V	2.0 pA (Max) @ 10 mV	200 pA @ 5 V	1.0 nA (Typ.) @ 20 V
Junction Capacitance	6 pF (Typ.) @ 10 V	140 pF (Typ.) @ 0 V	380 pF @ 5 V	24 pF (Typ.) @ 20 V

Fig.10 Different parameters between Si photodiodes
source: https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=285

Photoresistor

Photoresistor has another light dependent resistor (LDR) . The electric resistance is determined by number of incident photons .

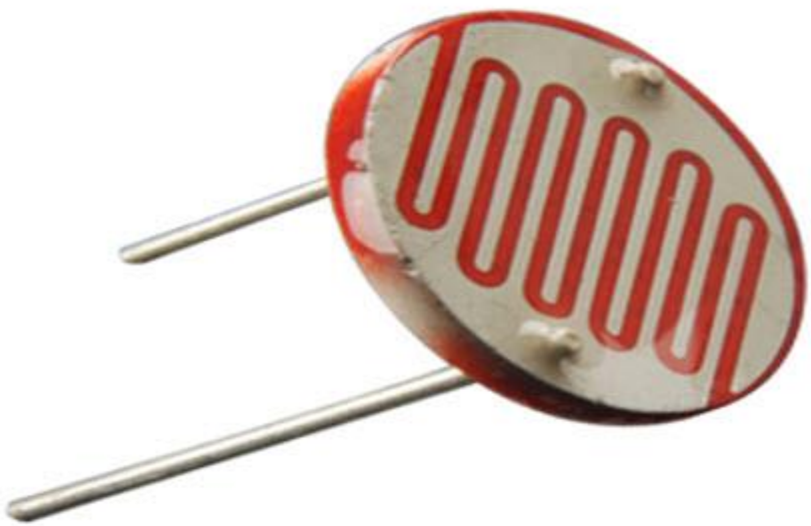


Fig11 : photoresistor (https://www.elprocus.com/ldr-light-dependent-resistor-circuit-and-working/)

Photoresistor

Photoresistor is made of semiconductor which has a special characteristic . The conduction of semiconductor is bad at the normal condition . But in some condition , the conduction would raise up . It is called conduction band .

Most of electrons inside photoresistor are valance electrons normally and the atom has strong attractive force to the electron . So the resistance of the conduction is huge for the electrons are hard to flow

Once the incident photons go in and provide energy to the valence electrons . The valence electron turned into free electron . The electrons could follow the voltage and flow . Thus , the resistance gets lower comparing to the initial condition.

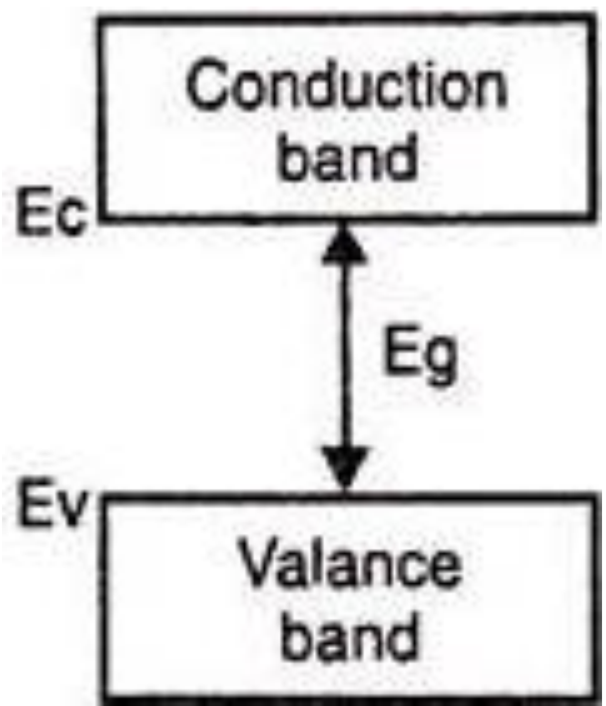


Fig12 : conduction band of semiconductor

Photoresistor _ main parameter

1. Temperature , humidity : The electric resistance is different in different environmental condition .
2. The relation between electric resistance and illumination ( ) : This depends on every different product and what to use .
3. Sensitivity of changing resistance : It means how much time from one Resistance to another take --- The time shouldn't be greater than the change of the light signal we are to measure .
4. Sensitivity of frequency of light :

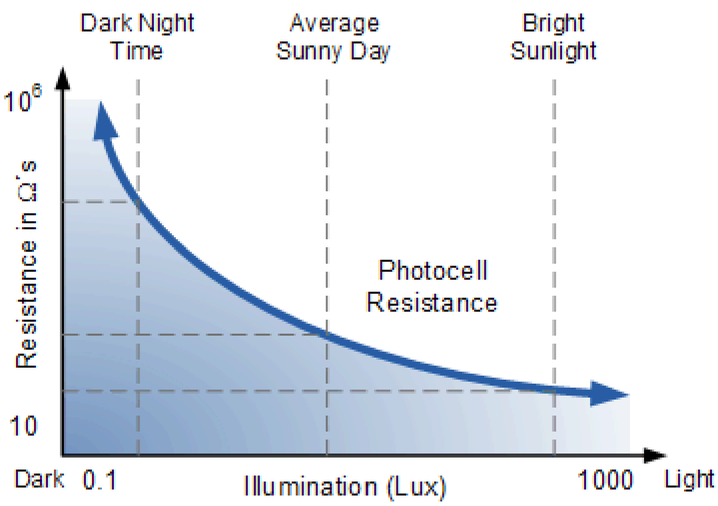


Fig13 : $R\ and\ lux$ (From: https://www.electronics-tutorials.ws/io/io_4.html)

Photomultiplier tube

Photomultiplier tube is an sensor that can enlarge the signal from photon .

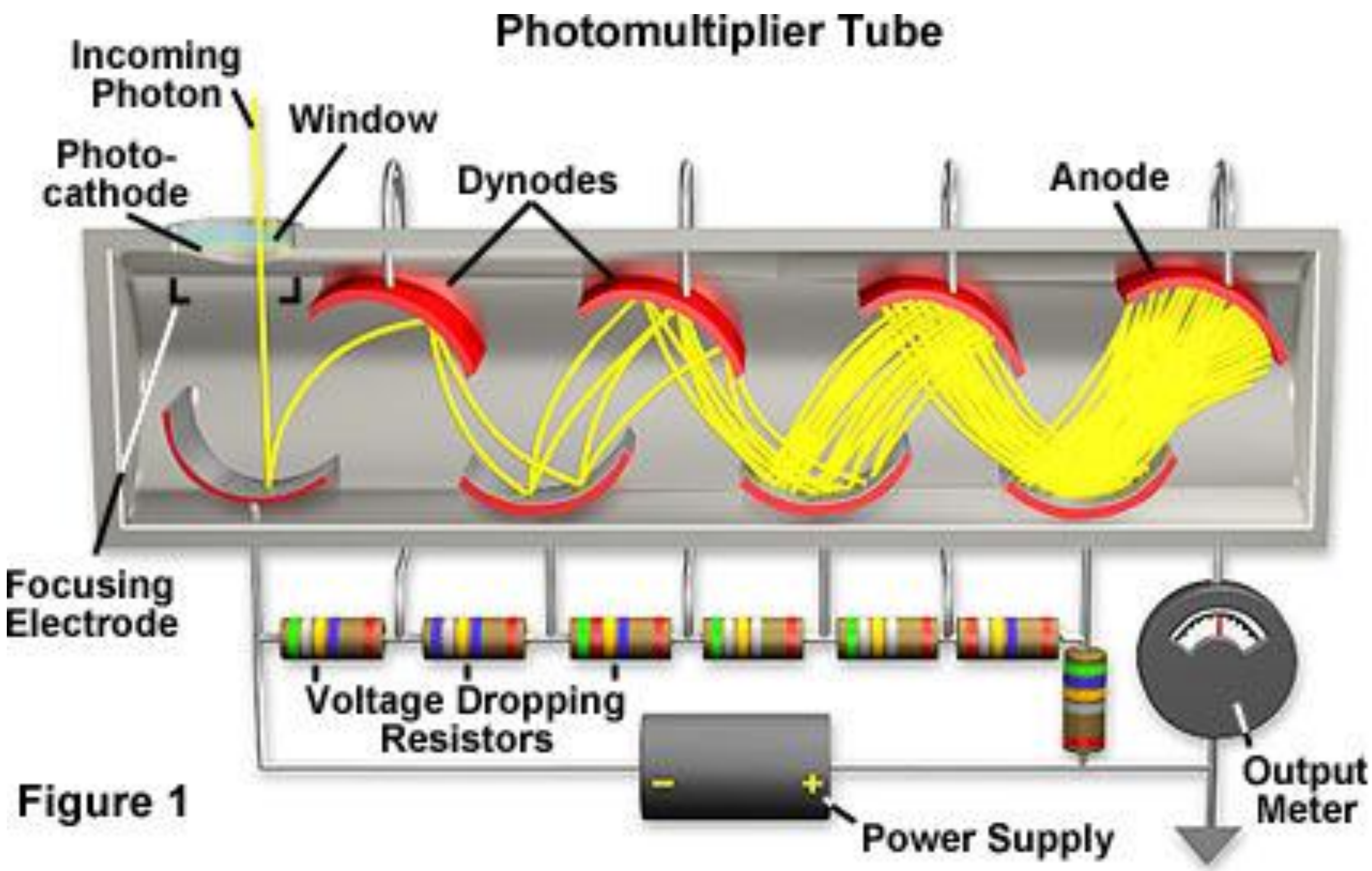


Fig14 : Basic structure of PMT (http://hamamatsu.magnet.fsu.edu/articles/photomultipliers.html)

Photomultiplier tube

When the incoming photon go inside PMT , it would hit the photocathode and then photocathode release electrons . The electron then hit a dynode .

Dynodes is made of material that has higher electric potential which make it easy for the valence electron to be free electron. Thus dynode receive the high E_k (primary) electron with high E_k and emit (secondary) electron . The amount of electron emitted by dynode are more than it received .

At the end , the anode collect all the electron and put into outer meter , recognizing the information the first photon carrying .

Photomultiplier tube

1. The number of incidents photons: It may cause the censor fatigue .

2. Working voltage: If the voltage goes too high , the electron may jump out of dynodes without the primary electron .

Photomultiplier tube VS Photodiode

	photodiode	photomultiplier
Noise	LOW	HIGH (For the process of electron transmit)
Sensitivity	Lower	Higher (For the signal has been enlarged by some precession.
Voltage consuming	Lower	Higher (Dynode needs more voltage to emit electron)
Complexity of structure	Lower	Higher (There are many dynode inside and they must have the right angle for the electron to pass on

Photoresistor VS Photodiode

1. Photoresistor is bidirectional (it’s like a Potentiometer)while Photodiode is confined to PN of PIN .

2. Photodiode usually have quicker response time than photoresistor.

3. Photoresistor is only reduce resistance by make electron free while photodiode is make the photoelectron and create electric current .

4. The resistance of photoresistor is only determine by light , while the photodiode would be impacted by external voltage .

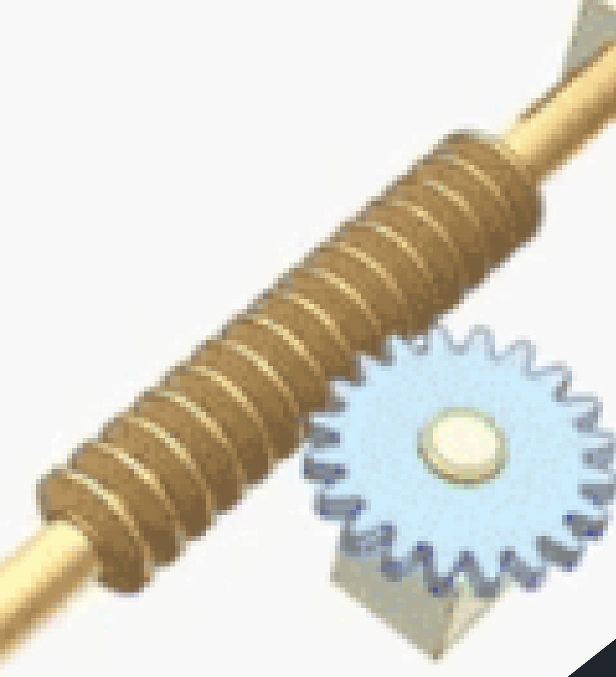


fig.1 rod

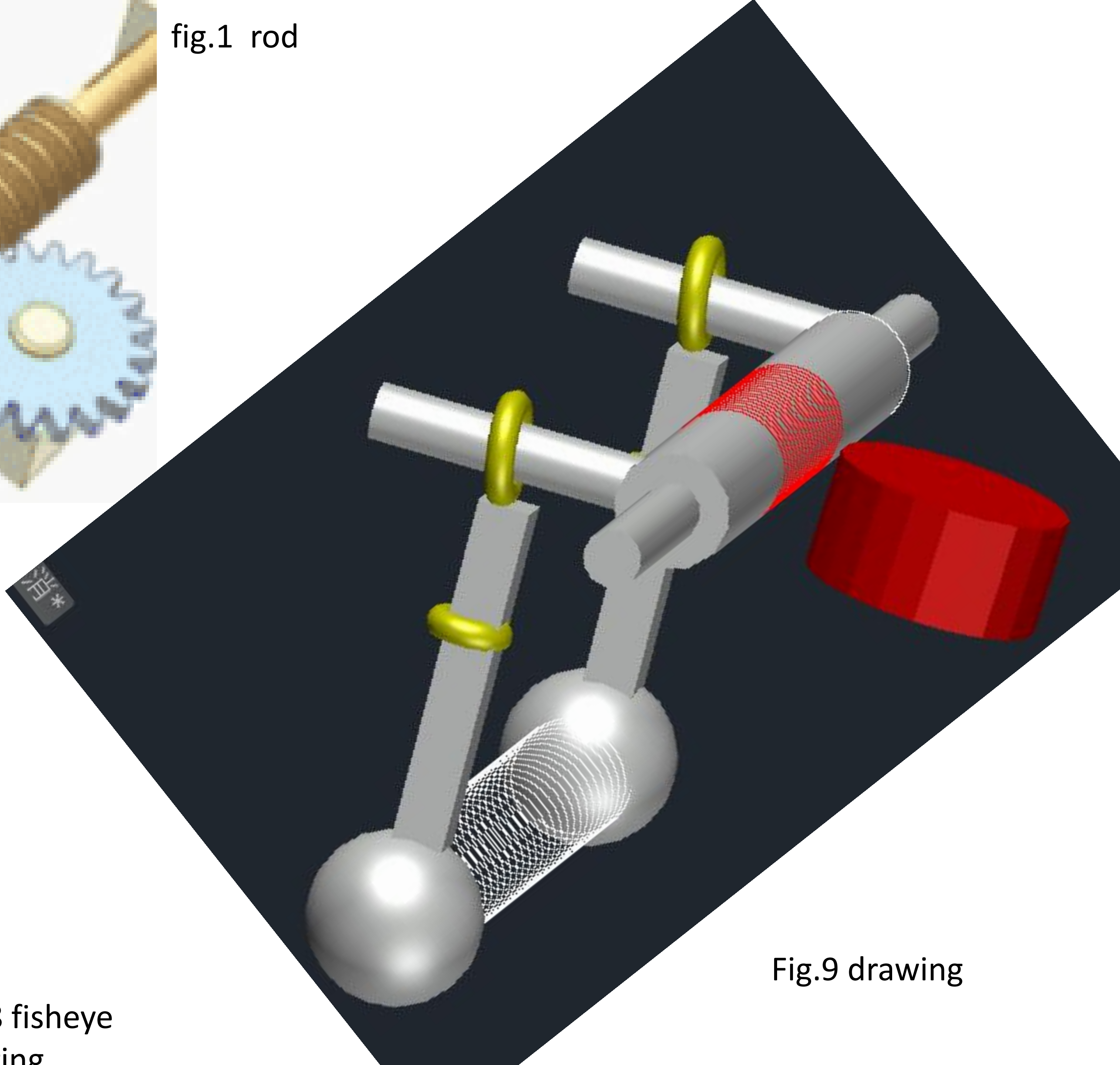


Fig.9 drawing

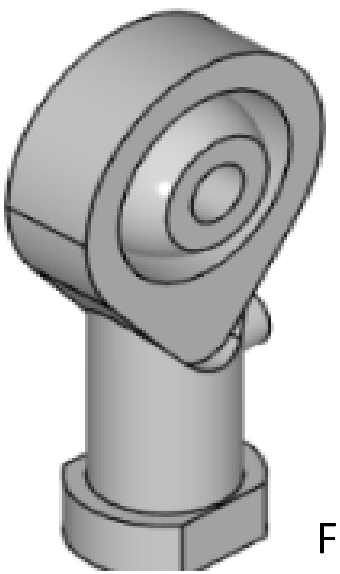


Fig.8 fisheye bearing

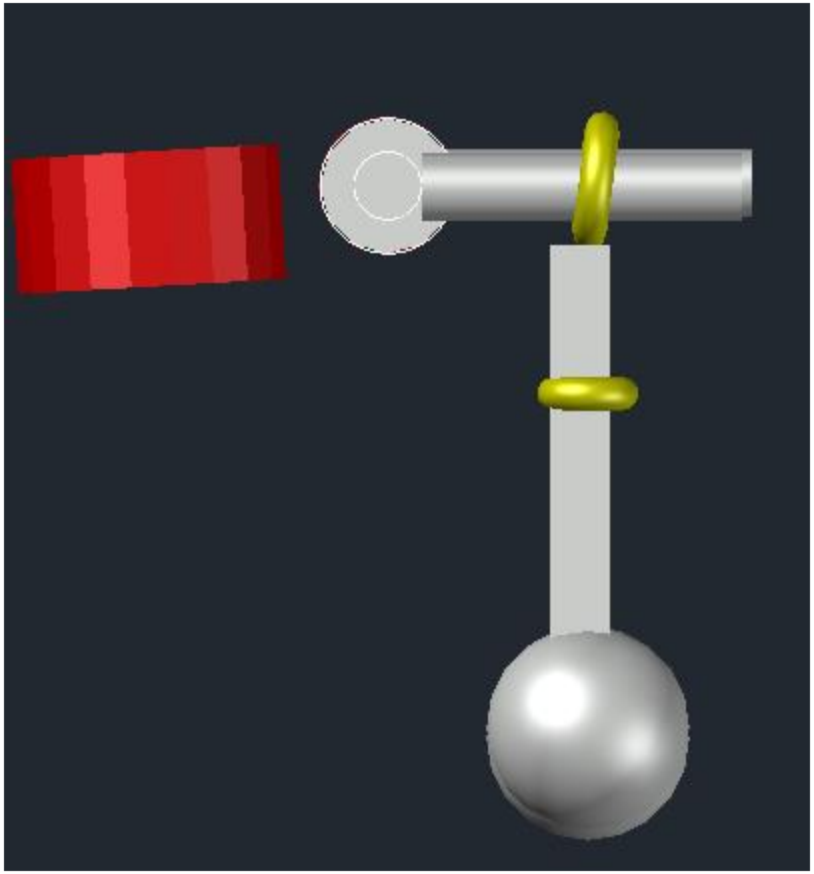


Fig.2 drawing

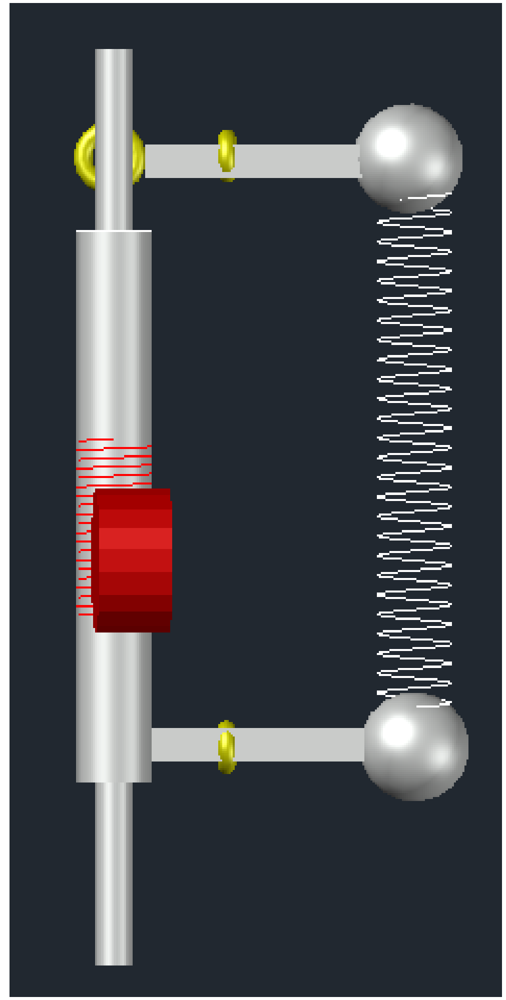


Fig.3 drawing

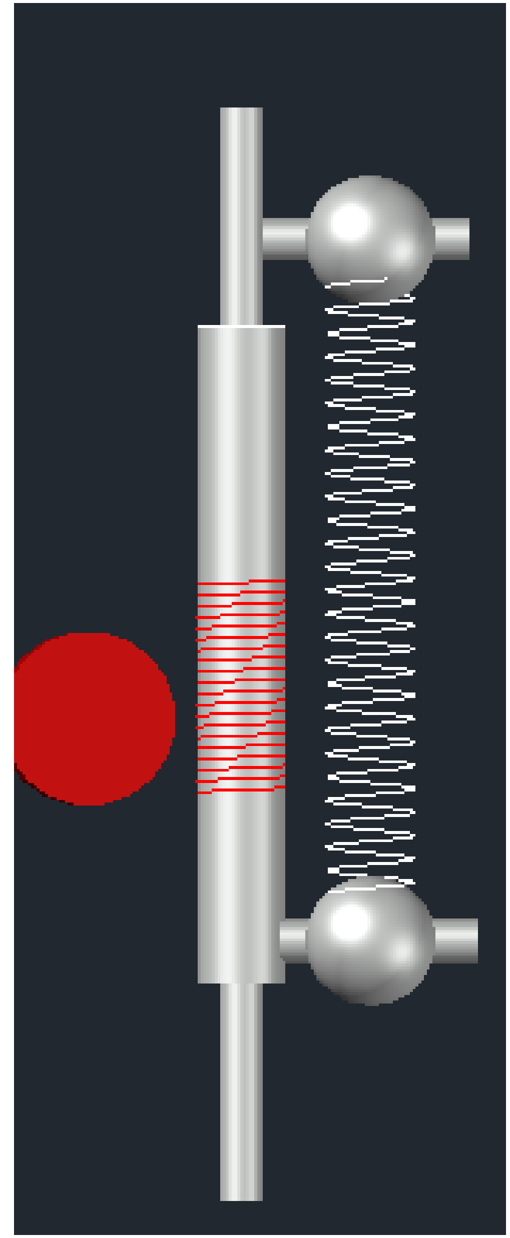


Fig.4 drawing

fig. 10 stepper motor

Stepper motor ________500

Fisheye bearing ________200

gear______100

aluminium______300

spring_______50

mental ball ______200

about_______1500

Aims:

1. Thin rod and thick rod are fixed. Simulate the norm
2. Thin rod is fixed. Stepper motor as an external forc

Measurement:

1. weight: pendulum, spring
2. Length: thread, spring
3. K: spring (with Weight)

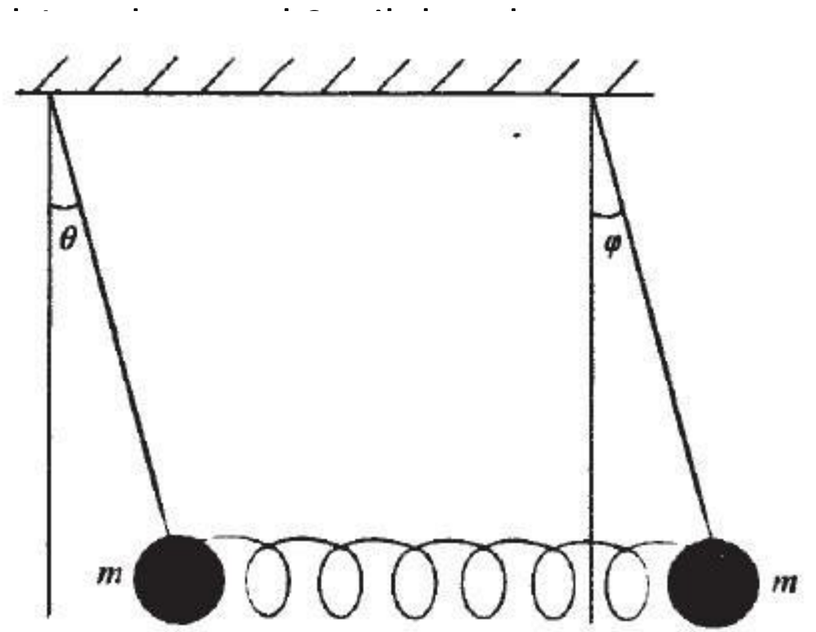


Fig.5 normal 1

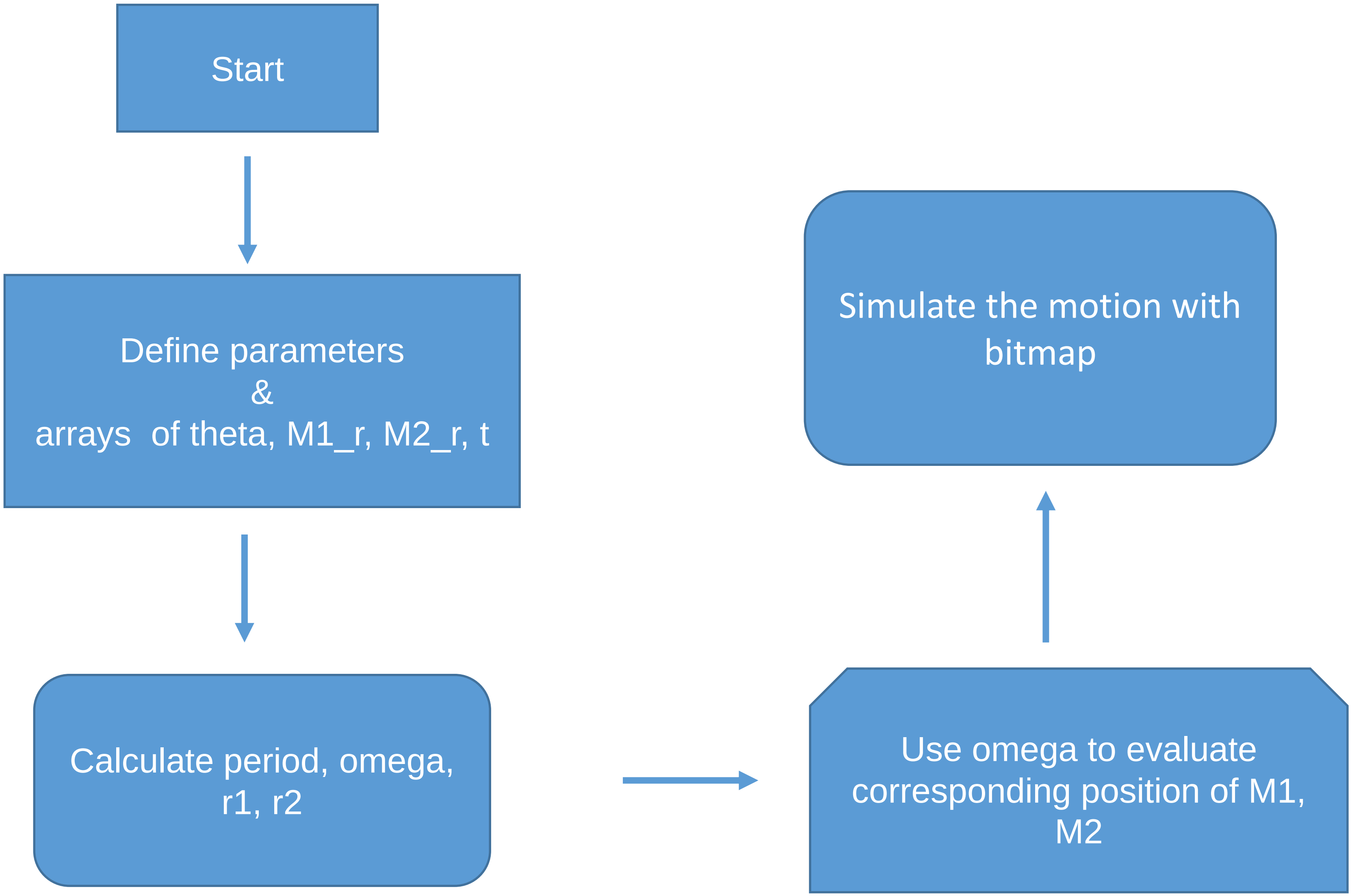
Schedule:

1. preparing: 1 week
2. Machining: 4 week
3. Experiment: 1 week
4. Report: 2 week

fig.1 http://www.axtoutiao.com/v294775
fig. 10 https://goods.ruten.com.tw/item/show?21942481194881
Fig. 5 https://m.doc.docsou.com/be48927388afd8b3cbb223b7e.html

VB Coding-葉揚昀 108202529

Flow Chart (Motion of double stars)



VB Coding-葉揚昀 108202529

Define parameters & arrays of theta, M1_r, M2_r, t

```
Dim time(1000000.0) As Single
Dim theta(10000000.0) As Single
Dim M1_r(10000000.0, 1) As Single
Dim M2_r(10000000.0, 1) As Single
Dim M1 As Single
Dim M2 As Single
Dim r_1 As Single
Dim r_2 As Single
Dim r1 As Single
Dim r2 As Single
Dim omega As Single
Dim omega_tru As Single
Dim i As Single = 1
```

VB Coding-葉揚昀 108202529

Calculate period, omega, r1, r2

```
Dim initial_theta As Single = CSng(Initial_theta_tex.Text)
Dim dt As Single = 100000
Dim G As Single = 0.0000000000667
Dim T As Single = 2 * PI * (L ^ 1.5) * Sqrt(1 / (G * (M1 + M2)))
omega_tru = 2 * PI / T
omega = omega_tru
r1 = M2 / (M1 + M2) * L
r2 = M1 / (M1 + M2) * L
time(0) = 0
theta(0) = initial_theta
M1_r(0, 0) = r1 * Cos(initial_theta)
M1_r(0, 1) = r1 * Sin(initial_theta)
M2_r(0, 0) = -r2 * Cos(initial_theta)
M2_r(0, 1) = -r2 * Sin(initial_theta)
```

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Use omega to evaluate corresponding position of M1, M2

```
While time(i) <= 10 * T
            time(i + 1) = time(i) + dt
            theta(i + 1) = theta(i) + omega * dt
            M1_r(i + 1, 0) = r1 * Cos(theta(i + 1))
            M1_r(i + 1, 1) = r1 * Sin(theta(i + 1))
            M2_r(i + 1, 0) = -r2 * Cos(theta(i + 1))
            M2_r(i + 1, 1) = -r2 * Sin(theta(i + 1))
            i = i + 1
        End While
```

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Simulate the motion with bitmap

```
If j <= i Then
            TextBox4.Text = "t = " + CStr(time(j)) + " (s)" + "      omega = " + 
CStr(omega_tru) + "   r1 = " + CStr(r1) + "  r2 = " + CStr(r2)
            TextBox5.Text += "i = " + CStr(j) + "   t = " + CStr(time(j)) + " (s)" + " 
theta = " + CStr(theta(j)) & vbCrLf


            brushh.Color = Color.Blue
            gra.FillPie(brushh, M1_r(j, 0) - r_1 / 2, M1_r(j, 1) - r_1 / 2, r_1, r_1, 0, 360)
            gra.FillPie(brushh, M2_r(j, 0) - r_2 / 2, M2_r(j, 1) - r_2 / 2, r_2, r_2, 0, 360)
            brushh.Color = Color.Red
            gra.FillPie(brushh, 0 - CM_r / 2, 0 - CM_r / 2, CM_r, CM_r, 0, 360)
            PictureBox1.Image = bitt
            j = j + 1
        ElseIf j > i Then
            j = 0
            TextBox4.Clear()
            TextBox5.Clear()
        End If
```

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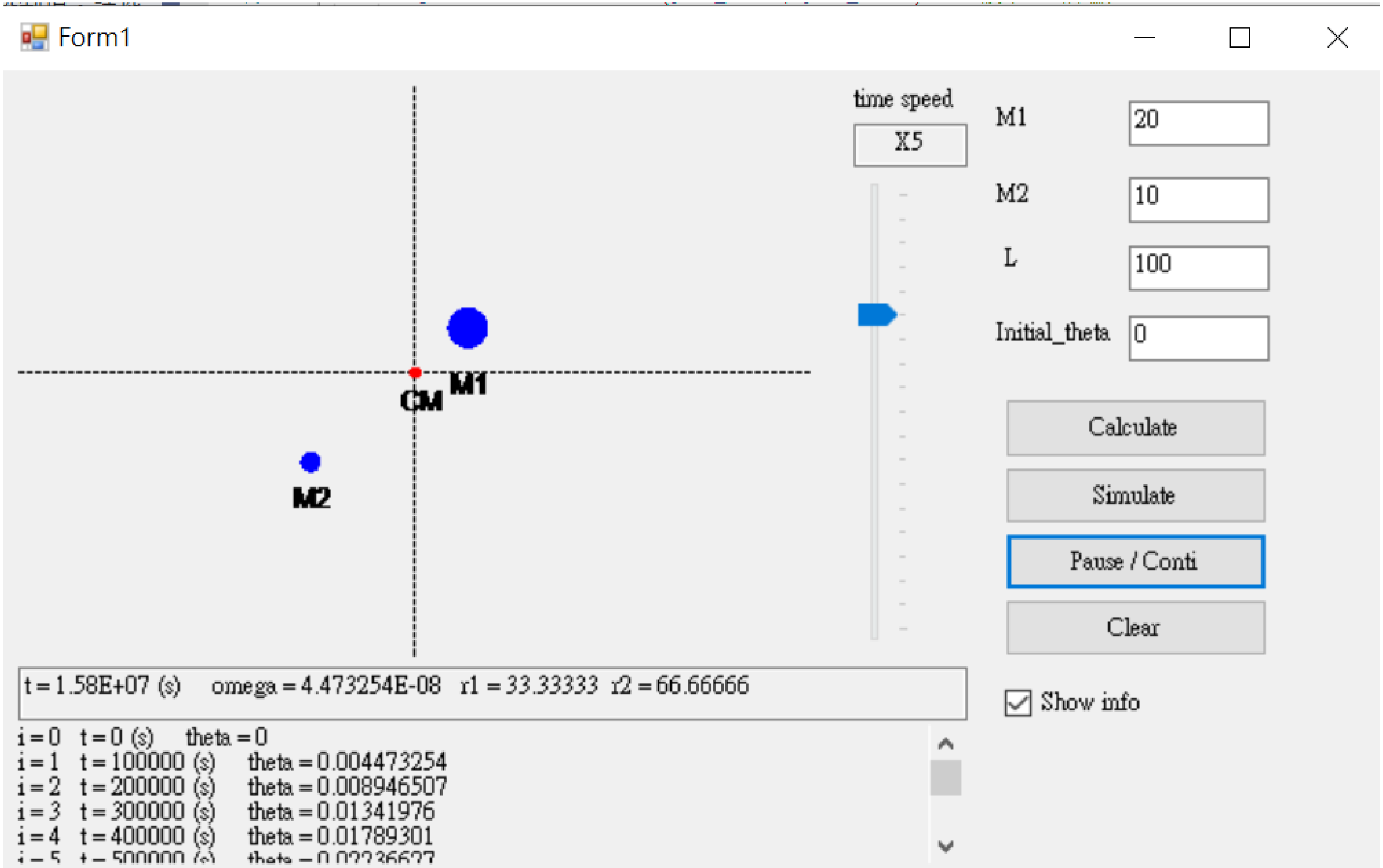
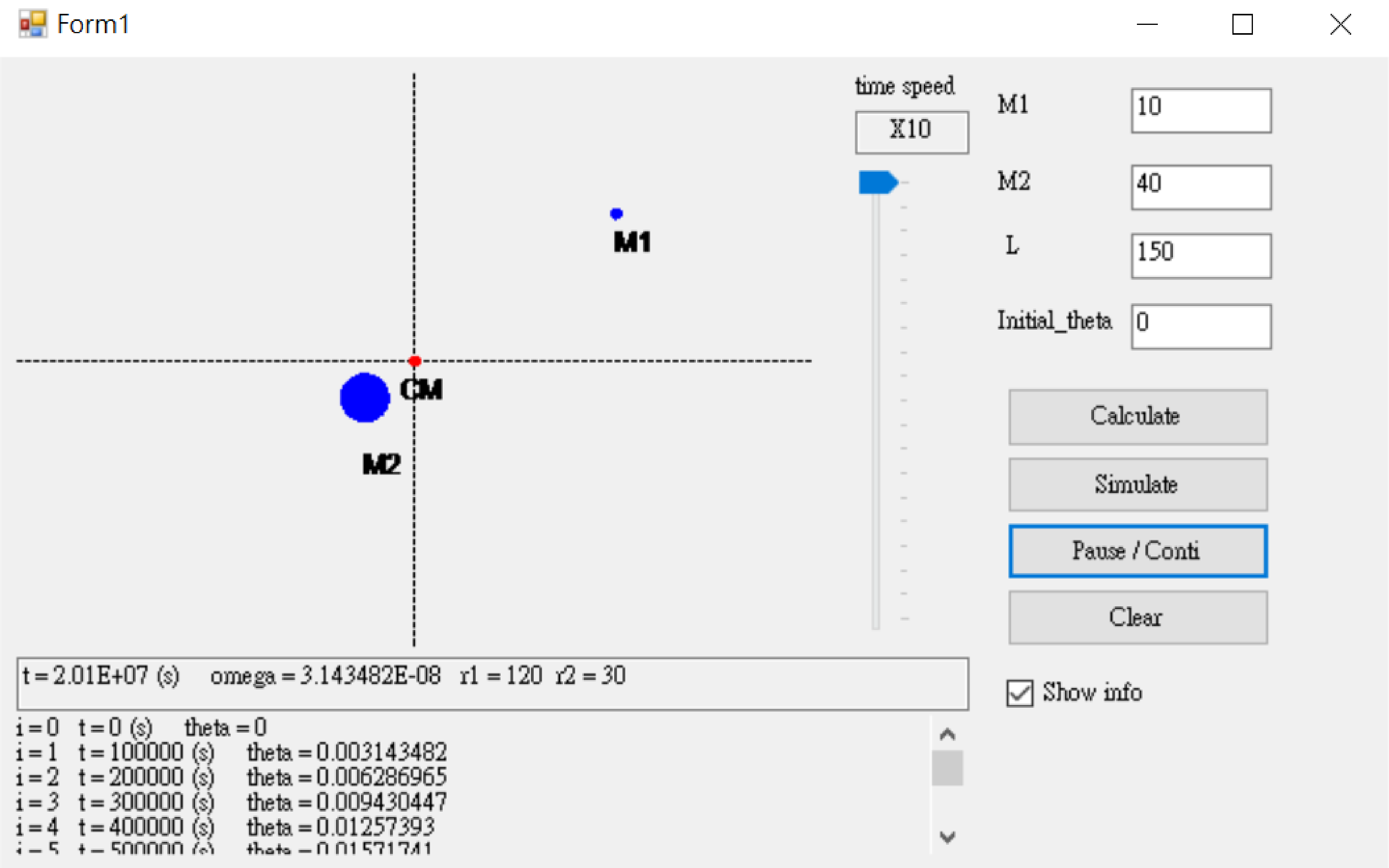
Result (L=100 (m) , M1= 20 (kg), M2= 10 (kg), dt = 100000 (s))



VB Coding-葉揚昀 108202529

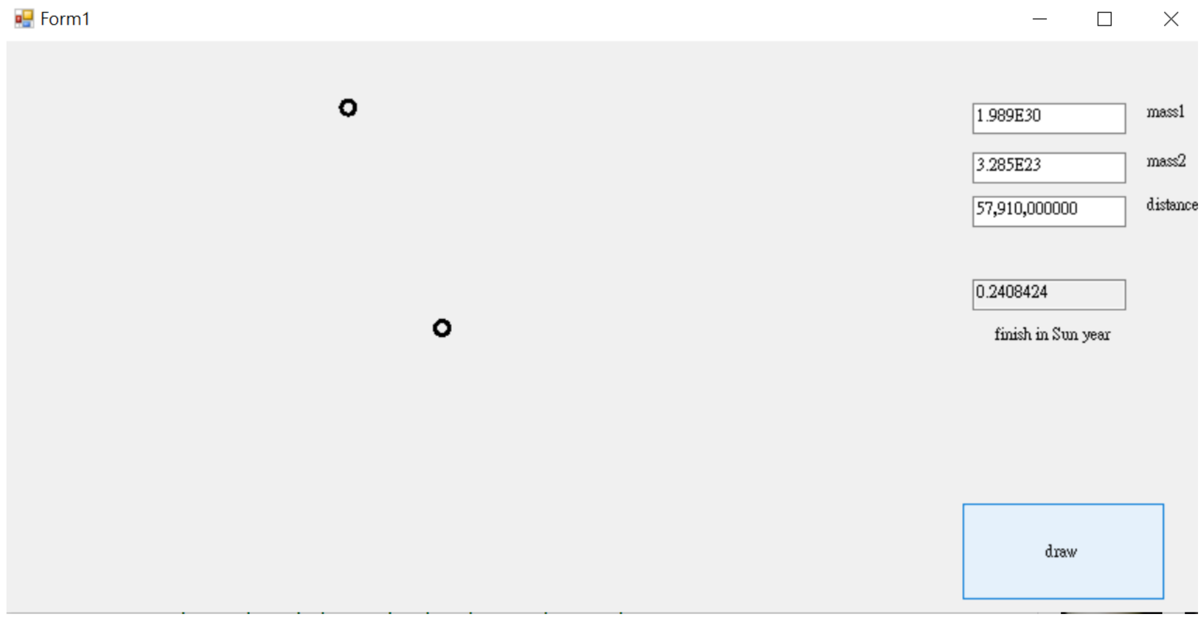
Result (L=150 (m) , M1= $10\ (kg)$, M2= $40\ (kg)$, dt = 100000 (s))



Vb_practice_田家瑋

The period of Mercury and sun finish is 88 days is about

$$\frac{88}{365} \cong 0.2411\ years$$



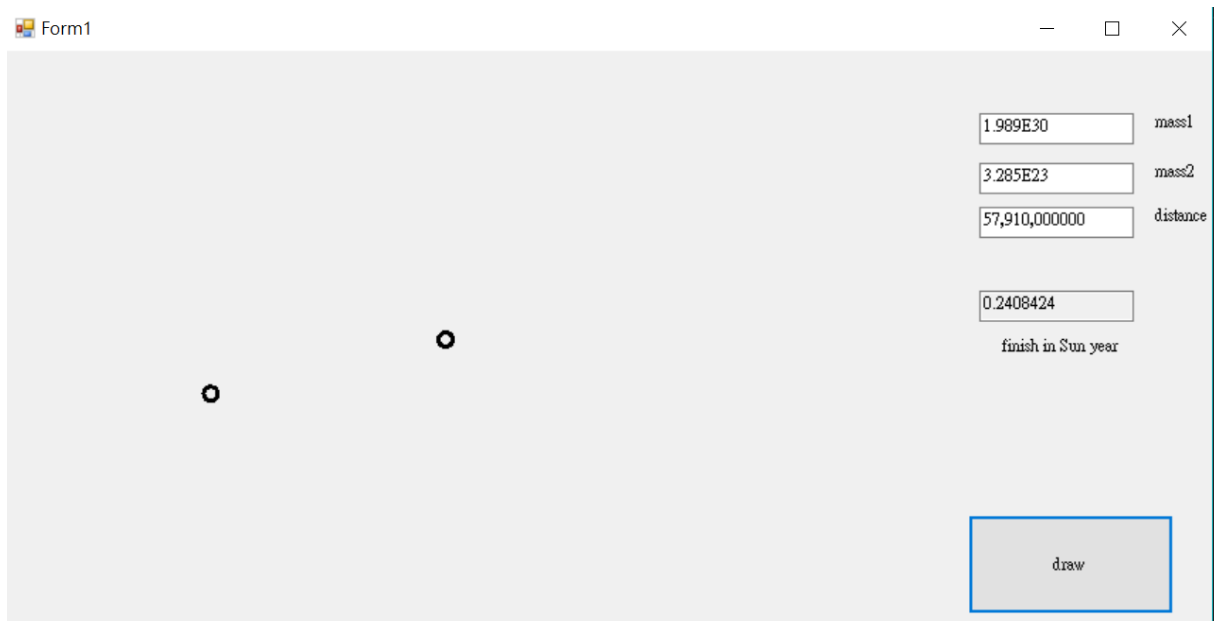
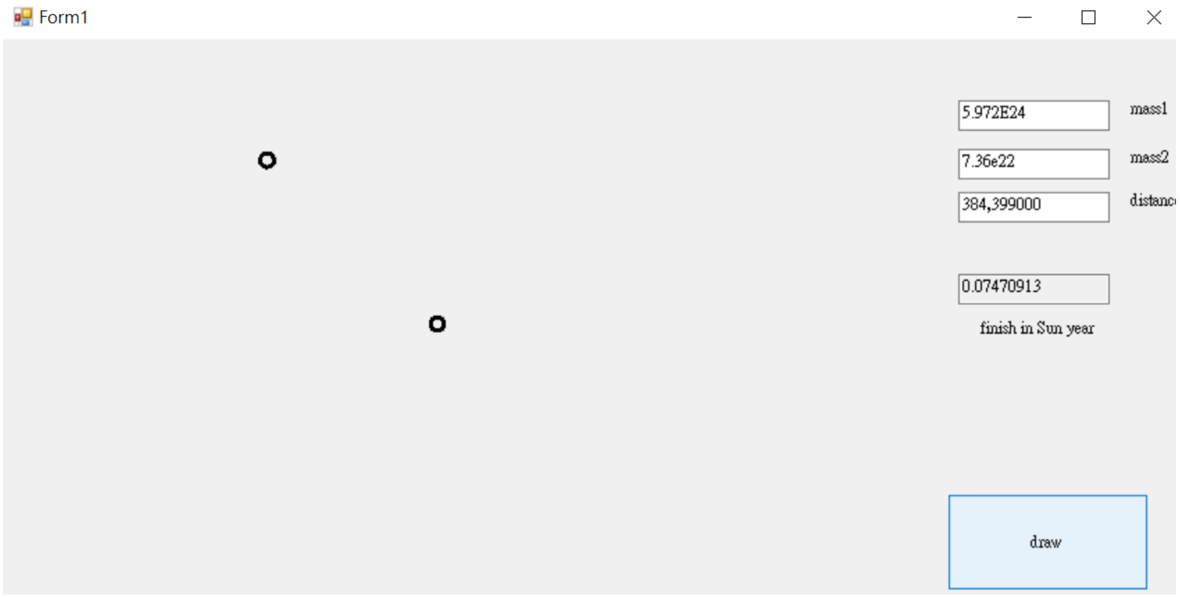


Fig1 and Fig2 : Mercury and Sun

Vb_practice_田家瑋

The period of Earth and moon finish is 27 days is about

$$\frac{27}{365} \cong 0.0.074\ years$$



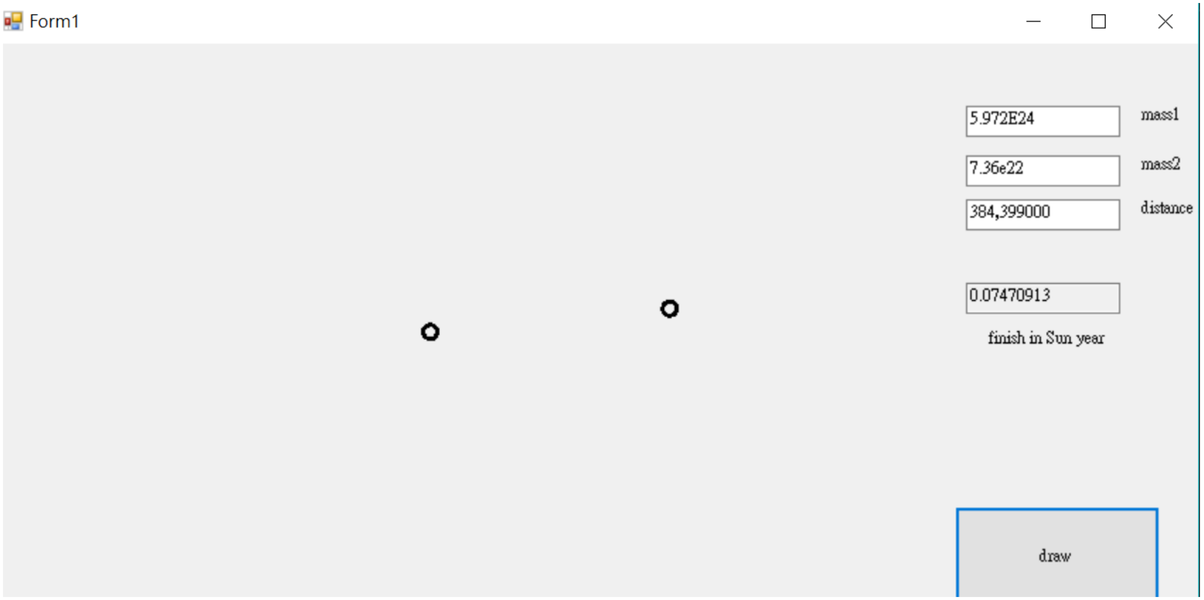


Fig3 and Fig4 : Moon and Earth

Vb_practice_田家瑋

Compute ω of double-star motion → Comparing to ω of sun → draw

Compute the period of the 2 double-star motion to Sun year

$$\frac{GMm}{R^2} = mr\omega^2$$

$$= m \cdot \frac{MR}{M+m} \cdot \omega^2$$

$$\omega^2 = G\frac{(M+m)}{R^3}$$

$$\omega = \sqrt{G\frac{(M+m)}{R^3}}$$

Use $\sin(\theta + \omega t)$ and $\cos(\theta + \omega t)$ to draw graphs

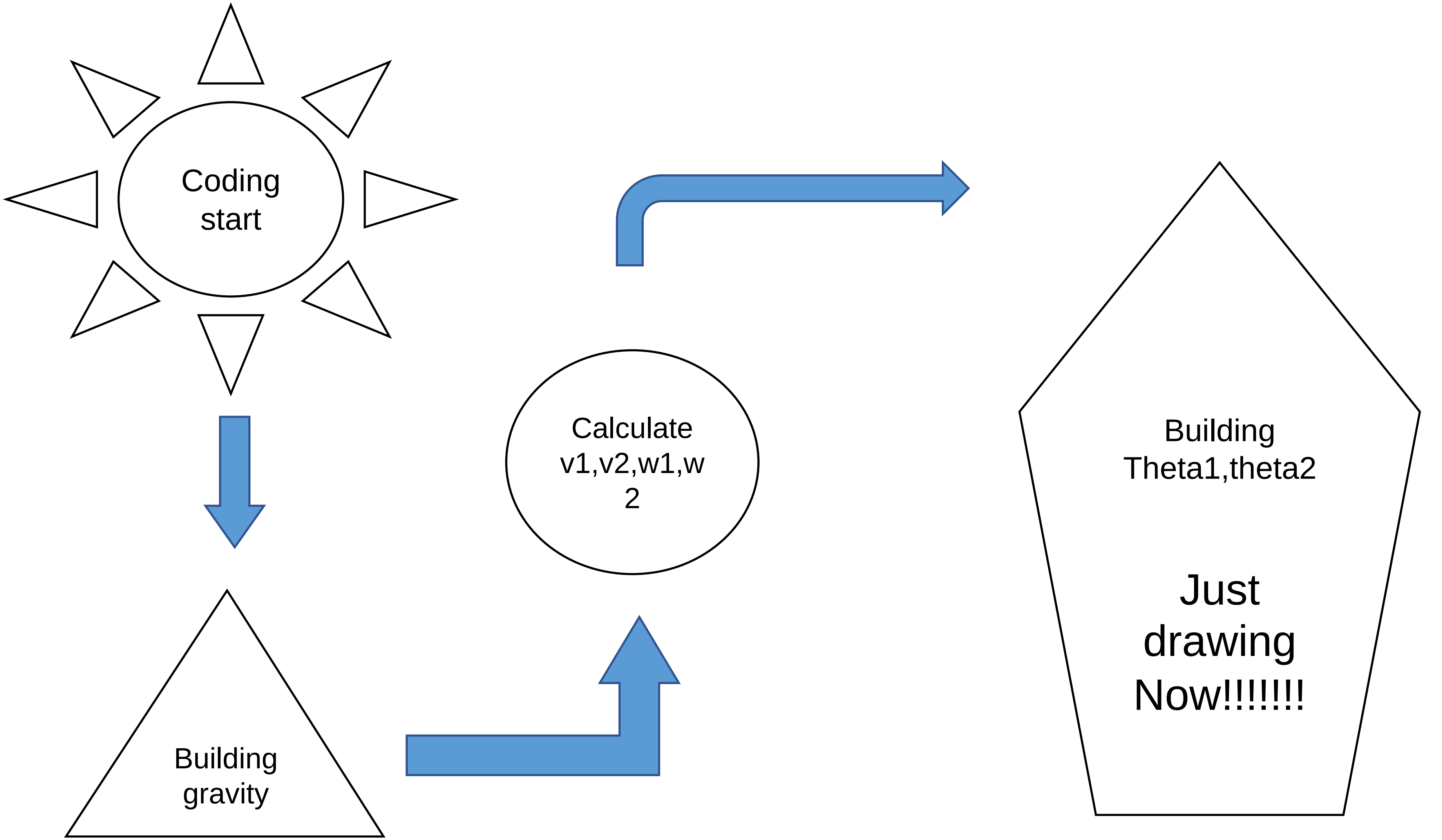
Vb_practice_compute_part_田家瑋

It’s in bottom .

```
 'set omega of the graph of Sun and earth = 2*pi / 90 '
Dim omega_ear As Single = Sqrt(G * (1.989E+30) / CSng(Pow(149600000000, 3)))


'set the input omega'
Dim omega_input As Single = Sqrt(G * (m1 + m2) / CSng(Pow(r, 3)))

'set how many input omaga equals to omega of sun
theta_1 = 2 * PI / 90 * omega_input / omega_ear
omega.Text = omega_ear / omega_input
```

Vb_practice_Timer_click_part_田家瑋

```
Private Sub Timer1_Tick(sender As Object, e As EventArgs) Handles Timer1.Tick
        PictureBox1.Image = Nothing
        Dim bitt As New Bitmap(PictureBox1.Width, PictureBox1.Height)

        'define graphic'
        Dim gra As Graphics = Graphics.FromImage(bitt)
        'define pen'
        Dim penn As Pen = New Pen(Color.Black, 3)
        'reset the origin of the coordinate’
        gra.TranslateTransform(0, 200)
        gra.ScaleTransform(1, -1)
        gra.TranslateTransform(120, 0)
        'm1'
        gra.DrawEllipse(penn, pixels + pixels * m2 / (m1 + m2) * CSng(Cos(theta_1 * i)), pixels * m2 / (m1 +
m2) * CSng(Sin(theta_1 * i)), 10, 10)
        'm2
        gra.DrawEllipse(penn, pixels - pixels * m1 / (m1 + m2) * CSng(Cos(theta_1 * i)), -pixels * m1 / (m1
+ m2) * CSng(Sin(theta_1 * i)), 10, 10)


        Dim imaaage As Image = DirectCast(bitt, Image)
        'Cast the image onto picturebox'
        i = i + 1
        PictureBox1.Image = imaaage
    End Sub
```


Coding
start
Building
gravity
Calculate
v1,v2,w1,w
2
Building
Theta1,theta2
Just
drawing
Now!!!!!!!

```
Dim l1 As Single = 40            ‘m1到質心的距離
Dim l2 As Single = 20            ‘m2到質心的距離
Dim g = 6.67                     ‘G=6.67 宇宙常數
Dim m1 = 10                      ‘質量
Dim m2 = 20
Dim v1, v2, w1, w2 As Single     ‘速度角速度
Dim t = 0
Dim theta1 As Single = 0         ‘角度
Dim theta2 As Single = 0
Dim f As Single                  ‘萬有引力
Dim penn As New Pen(Color.Blue, 1)
Dim pennn As New Pen(Color.Red, 2)
Dim mline1, mline2, mline3, mline4 As Single
```

```
Dim f As Single
f = g * m1 * m2 / ((l1 + l2) * (l1 + l2))      '萬有引力
v1 = Math.Sqrt(f * l1 / m1)
w1 = v1 / l1
v2 = Math.Sqrt(f * l2 / m2)
w2 = v2 / l2
t = t + 1
theta1 = theta1 + w1 * t
theta2 = theta2 + w2 * t
mline1 = l1 * Cos(theta1)          'm1的x路徑
mline2 = l1 * Sin(theta1)          'm1的y路徑
mline3 = l2 * Cos(theta2)            'm2的x路徑
mline4 = l2 * Sin(theta2)             'm2的y路徑
Dim bitt As New Bitmap(PictureBox1.Width, PictureBox1.Height)
Dim pic As Graphics = Graphics.FromImage(bitt)
Dim pic2 As Graphics = Graphics.FromImage(bitt)
pic.TranslateTransform(320, 200)
pic.DrawEllipse(penn, mline1, mline2, 5, -5)             '畫m1
pic2.TranslateTransform(320, 200)
pic2.DrawEllipse(pennn, -mline3, mline4, 8, -8)          '畫m2
Dim imaage As Image = DirectCast(bitt, Image)
PictureBox1.Image = imaage
```