18BEBME501 BIO CONTROL SYSTEM 3 2 0 4 100

UNIT I INTRODUCTION TO BIO CONTROL SYSTEM (9)

Introduction: Technological control system, transfer function, mathematical approaches, system stability, introduction to biological control system, Modeling and block diagram, closed loop dynamics of first order and second order control system, similarities between biological and engineering control system, biological receptors and receptor characteristics.

UNIT II PROCESS REGULATION (9)

Acid-base balance, extra-cellular water and electrolyte, interstitial fluid volume, blood pressure, blood glucose, CO2.

UNIT III MODELING OF HUMAN THERMAL REGULATORY SYSTEM (9)

Parameters involved, control system model etc. Biochemistry of digestion, types of heat loss from body, models of heat transfer between subsystems of human body like skin - core etc. and systems like within body, body environment.

UNIT IV BIOLOGICAL CONTROL I (9)

Cardiac rate, blood pressure, respiratory rate, mass balancing of lungs, oxygen uptake by RBC and pulmonary capillaries, oxygen and carbon dioxide transport in blood and tissues.

UNIT V BIOLOGICAL CONTROL II (9)

Urine formation and control, Pupil control systems, skeletal muscle servomechanism and semicircular canal. Free swinging limbs, Endocrine control system.

Total periods : 45

TEXT BOOKS

S.NO.	Author(s) Name	Title of the book	Publisher	Year of publication
1	Sujit K.Chaudhuri	Concise Medical Physilogy	New Central Book agency	1997
2	Ogata Katsuhika	Modern control engineering	2nd edition, Prentice Hall of India	-

REFERENCE BOOKS:

S.NO.	Author(s) Name	Title of the book	Publisher	Year of publication
1	Barry R. Dworkin	Learning and Physiological Regulation (Hardcover)	University Of Chicago Press	March 1993
2	E. Carson, E. Salzsieder	Modelling and Control in Biomedical Systems 2000 (including Biological Systems)	Pergamon Publishing	January 2001

UNIT 1
INTRODUCTION TO BIO CONTROL SYSTEM

Control system:

A system consists of a number of components connected together to perform a specific function. In a system when the output quantity is controlled by varying the input quantity, then the system is called control system. The output quantity is called controlled variable or response and input quantity is called command signal or excitation.

Open loop system:

Any physical system which does not automatically correct the variation in its output, is called an ***open loop system***, or control system in which the output quantity has no effect upon the input quantity are called open-loop control system. This means that the output is not fedback to the input for correction.

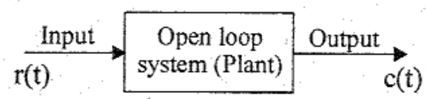
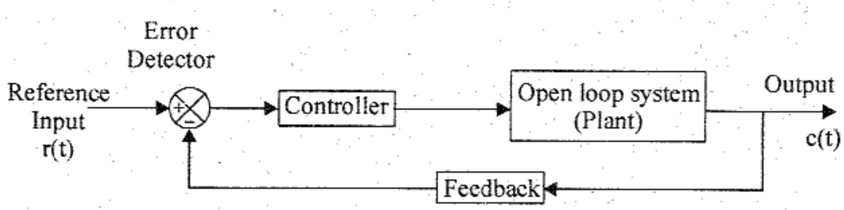


Fig 1.1 : *Open loop system.*

In open loop system the output can be varied by varying the input. But due to external disturbances the system output may change. When the output changes due to disturbances, it is not followed by changes in input to correct the output. In open loop systems the changes in output are corrected by changing the input manually.

Closed loop system:

Control systems in which the output has an effect upon the input quantity in order to maintain the desired output value are called ***closed loop systems.***



The open loop system can be modified as closed loop system by providing a feedback. The provision of feedback automatically corrects the changes in output due to disturbances. Hence the closed loop system is also called ***automatic control system.*** The general block diagram of an automatic control system is shown in fig 1.2. It consists of an error detector, a controller, plant (open loop system) and feedback path elements.

The reference signal (or input signal) corresponds to desired output. The feedback path elements samples the output and converts it to a signal of same type as that of reference signal. The feedback signal is proportional to output signal and it is fed to the error detector. The error signal generated by the error detector is the difference between reference signal and feedback signal. The controller modifies and amplifies the error signal to produce better control action. The modified error signal is fed to the plant to correct its output.

Advantages and Disadvantages of open loop system:

Advantages of open loop systems

1. The open loop systems are simple and economical.
2. The open loop systems are easier to construct.
3. Generally the open loop systems are stable.

Disadvantages of open loop systems

1. The open loop systems are inaccurate and unreliable.
2. The changes in the output due to external disturbances are not corrected automatically.

Advantages and Disadvantages of closed loop system:

Advantages of closed loop systems

1. The closed loop systems are accurate.
2. The closed loop systems are accurate even in the presence of non-linearities.
3. The sensitivity of the systems may be made small to make the system more stable.
4. The closed loop systems are less affected by noise.

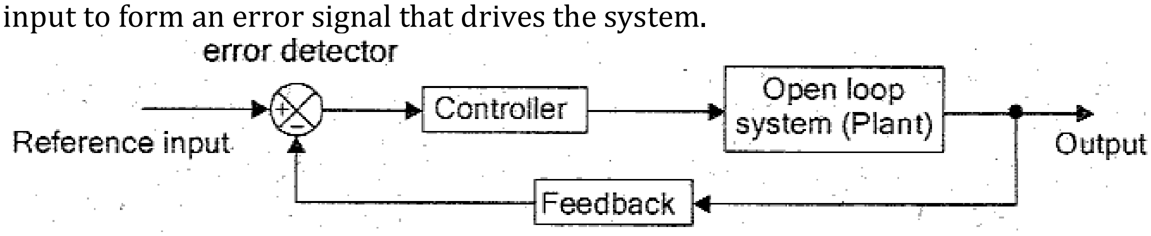
Disadvantages of closed loop systems

1. The closed loop systems are complex and costly.
2. The feedback in closed loop system may lead to oscillatory response.
3. The feedback reduces the overall gain of the system.
4. Stability is a major problem in closed loop system and more care is needed to design a stable closed loop system.

Open loop	Closed loop
1. Inaccurate & unreliable.	1. Accurate & reliable.
2. Simple and economical.	2. Complex and costly.
3. Changes in output due to external disturbances are not corrected automatically.	3. Changes in output due to external disturbances are corrected automatically.
4. They are generally stable.	4. Great efforts are needed to design a stable system.

Feedback systems

A feedback system is one in which the output signal is sampled and then fed back to the input to form an error signal that drives the system.



There are two types of feedback systems:

a)**Positive feedback systems**
In a "positive feedback control system", the set point and output values are added together by the controller as the feedback is "in-phase" with the input. The effect of positive (or regenerative) feedback is to "increase" the systems gain, i.e, the overall gain with positive feedback applied will be greater than the gain without feedback

a)**Negative feedback systems**
In a "negative feedback control system", the set point and output values are subtracted from each other as the feedback is "out-of-phase" with the original input. The effect of negative (or degenerative) feedback is to "reduce" the gain.

Transfer Function:
The transfer function of a system is defined as the ratio of Laplace transform of output to Laplace transform of input with zero initial conditions. (It is also defined as the Laplace transform of the impulse response of system with zero initial conditions).

Need of laplace transform:

The input output relations of various physical components of a system are governed by ***differential equations.*** The mathematical model of a control system constitutes a set of differential equations. The response or output of the system can be studied by solving the differential equations for various input conditions.

The transfer function can be obtained by taking Laplace transform of the differential equations governing the system with zero initial conditions and rearranging the resulting algebraic equations to get the ratio of output to input.

Impulse Response:
A signal which is available for very short duration is called impulse signal. Ideal impulse signal is a unit impulse signal which is defined as a signal having zero values at all time except at t = 0. At t = 0 the magnitude becomes infinite. It is denoted by δ(t) and mathematically expressed as,

$$\delta(t) = \infty \;;\; t = 0 \qquad = 0 \;;\; t = 0 \qquad \text{and} \qquad \int_{-\infty}^{+\infty} \delta(t)\, dt = 1$$

Damping Ratio:
The standard form of closed loop transfer function of second order system is given by,

$$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

where, ω_n = Undamped natural frequency, rad/sec.

ζ = Damping ratio.

The damping ratio is defined as the ratio of actual damping to critical damping.

Types of system based on damping ratio:

Depending on the value of damping, the system can be classified into the following four cases.

Case 1 : Undamped system, $\zeta = 0$

Case 2 : Underdamped system, $0 < \zeta < 1$

Case 3 : Critically damped system, $\zeta = 1$

Case 4 : Over damped system, $\zeta > 1$

The formula for transfer function for first order system:

$$\textbf{Transfer function} = \frac{G(s)}{1+G(s)H(s)}$$

The closed loop order system with unity feedback is shown in fig 2.6.

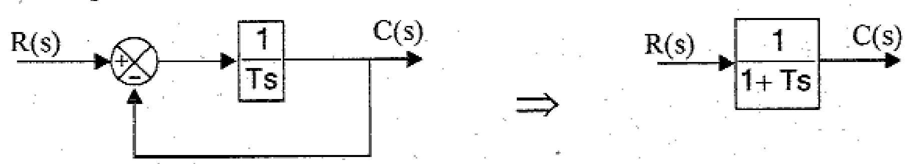


Fig 2.6 : Closed loop for first order system.

The closed loop transfer function of first order system, $\frac{C(s)}{R(s)} = \frac{1}{1+Ts}$

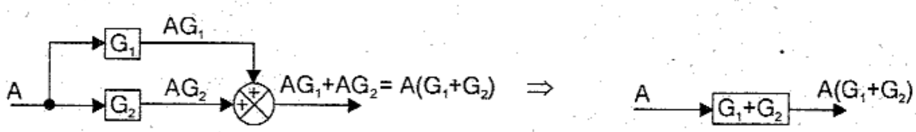
CK DIAGRAM REDUCTION

The block diagram can be reduced to find the overall transfer function of the system. The following rules can be used ock diagram reduction . The rules are framed such that any modification made on the diagram does not alter the input-output ation.

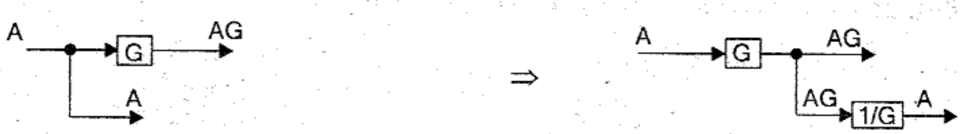
RULES OF BLOCK DIAGRAM ALGEBRA

Rule-1 : ***Combining the blocks in cascade***

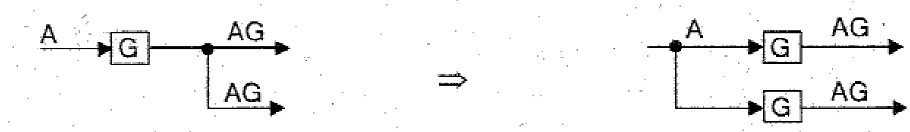
Rule-2 : ***Combining Parallel blocks (or combining feed forward paths)***



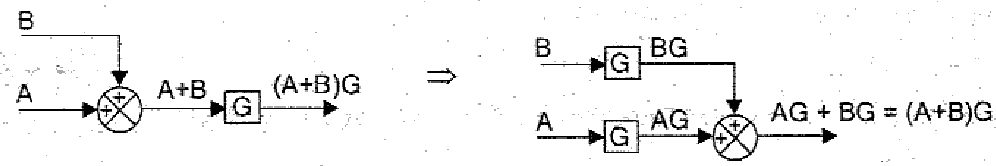
Rule-3 : ***Moving the branch point ahead of the block***



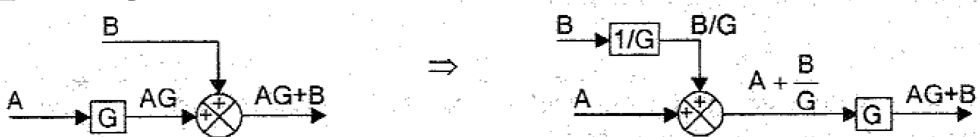
Rule-4 : ***Moving the branch point before the block***



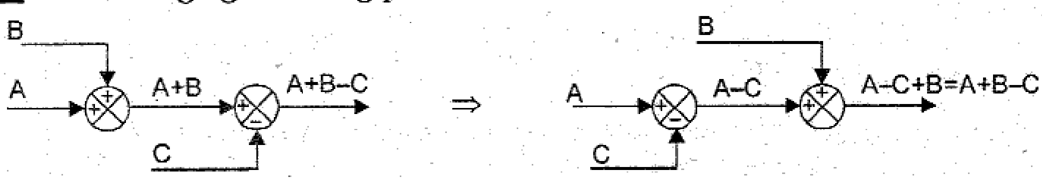
Rule-5 : ***Moving the summing point ahead of the block***



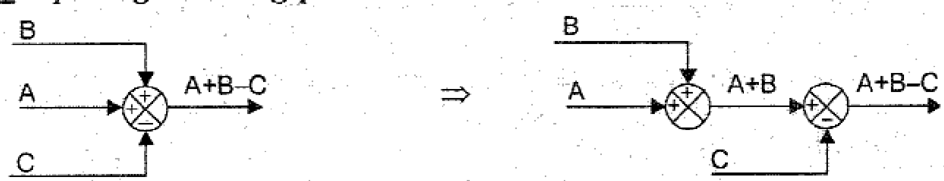
Rule-6 : ***Moving the summing point before the block***



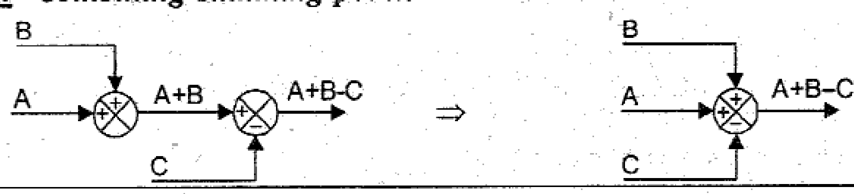
Rule-7 : ***Interchanging summing point***



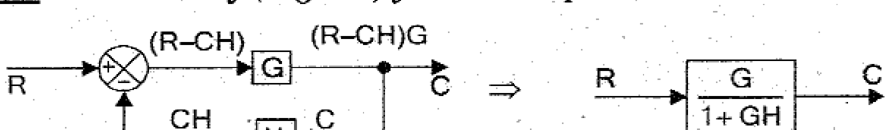
Rule-8 : ***Splitting summing points***



Rule-9 : ***Combining summing points***



Rule-10 : ***Elimination of (negative) feedback loop***

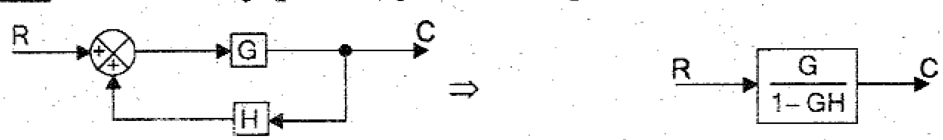


Proof:

$C = (R - CH)G \Rightarrow C = RG - CHG \Rightarrow C + CHG = RG$

$\therefore C(1 + HG) = RG \Rightarrow \frac{C}{R} = \frac{G}{1 + GH}$

Rule-11 : Elimination of (positive) feedback loop



EXAMPLE 1.17

Using block diagram reduction technique find closed loop transfer function of the system whose block diagram is sho in fig 1.

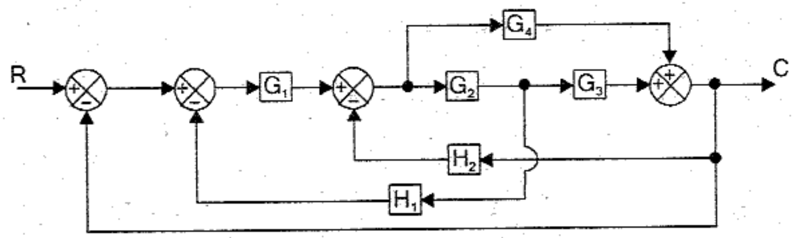
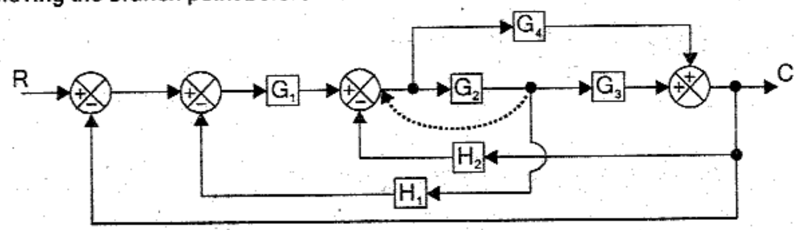


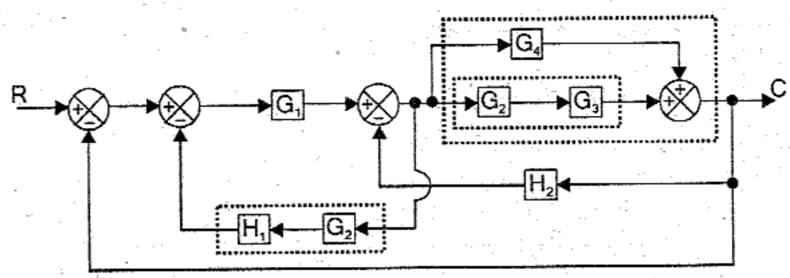
Fig 1.

SOLUTION

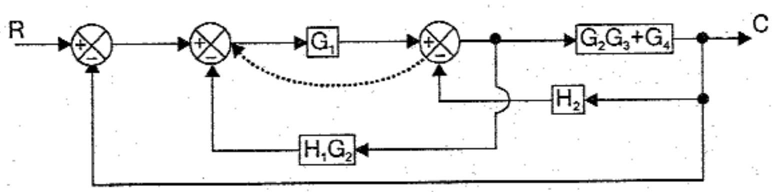
Step 1: Moving the branch point before the block



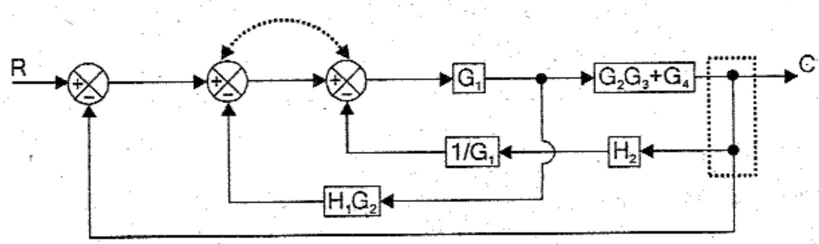
Step 2: Combining the blocks in cascade and eliminating parallel blocks



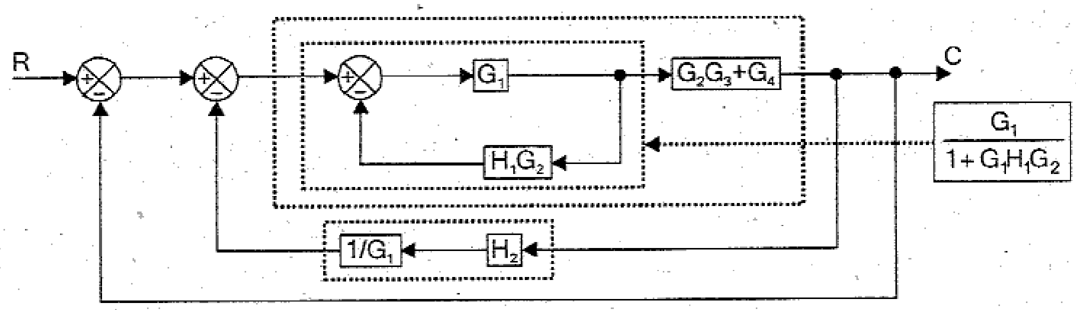
Step 3: Moving summing point before the block.



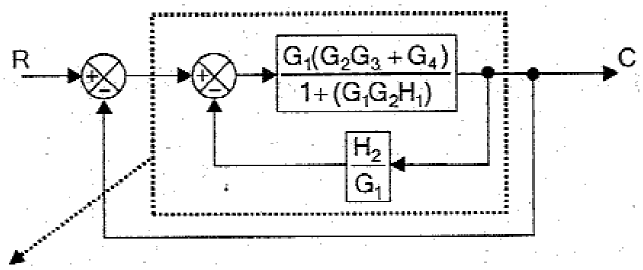
Step 4: Interchanging summing points and modifying branch points.



Step 5: Eliminating the feedback path and combining blocks in cascade

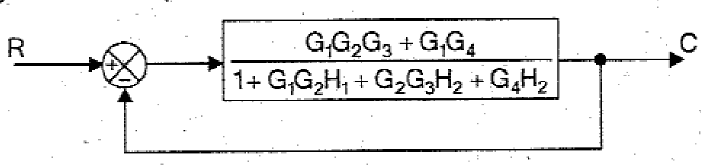


Step 6: Eliminating the feedback path



$$\frac{\frac{G_1(G_2G_3+G_4)}{1+G_1G_2H_1}}{1+\frac{G_1(G_2G_3+G_4)}{1+G_1G_2H_1}\,\frac{H_2}{G_1}} \Rightarrow \frac{\frac{G_1G_2G_3+G_1G_4}{1+G_1G_2H_1}}{\frac{1+G_1G_2H_1+G_2G_3H_2+G_4H_2}{1+G_1G_2H_1}} \Rightarrow \frac{G_1G_2G_3+G_1G_4}{1+G_1G_2H_1+G_2G_3H_2+G_4H_2}$$

Step 7: Eliminating the feedback path



$$\frac{C}{R}=\frac{\frac{G_1G_2G_3+G_1G_4}{1+G_1G_2H_1+G_2G_3H_2+G_4H_2}}{1+\frac{G_1G_2G_3+G_1G_4}{1+G_1G_2H_1+G_2G_3H_2+G_4H_2}} = \frac{G_1G_2G_3+G_1G_4}{1+G_1G_2H_1+G_2G_3H_2+G_4H_2+G_1G_2G_3+G_1G_4}$$

ESULT

The overall transfer function is given by,

$$\frac{C}{R}=\frac{G_1G_2G_3+G_1G_4}{1+G_1G_2H_1+G_2G_3H_2+G_4H_2+G_1G_2G_3+G_1G_4}$$

Determine the overall transfer function $\frac{C(s)}{R(s)}$ for the system shown in fig 1.

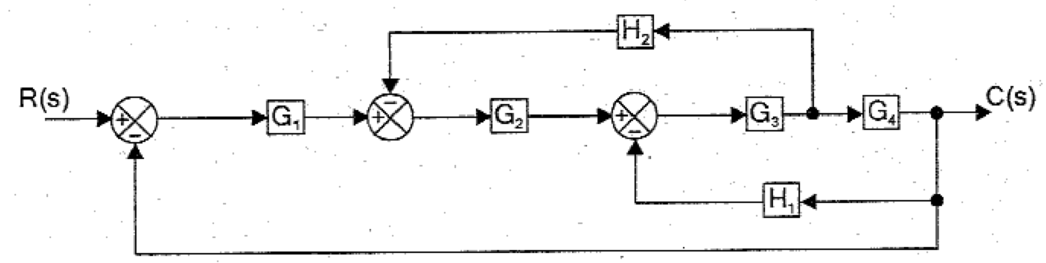
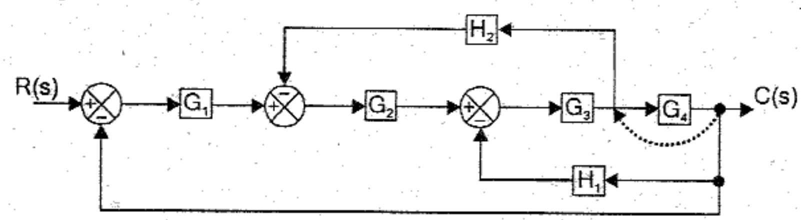


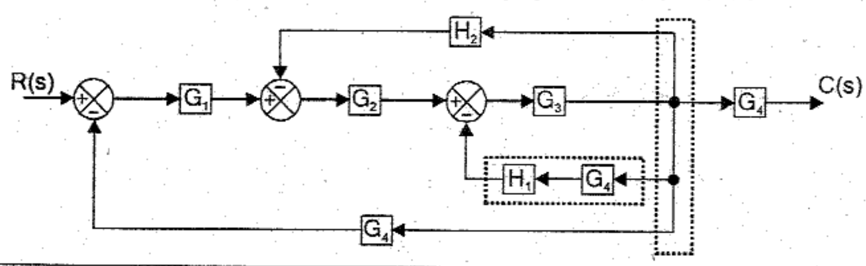
Fig 1

SOLUTION

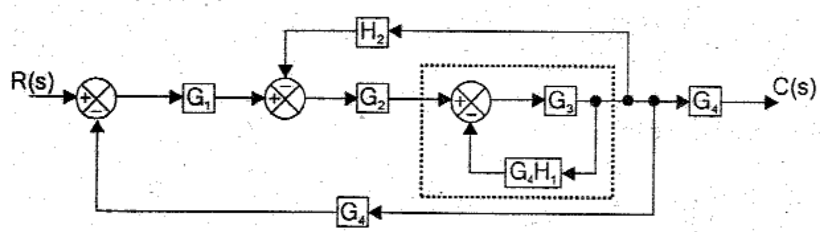
Step 1: Moving the branch point before the block



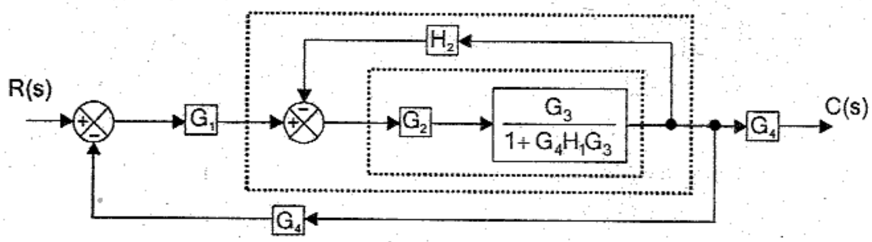
Step 2: Combining the blocks in cascade and rearranging the branch points



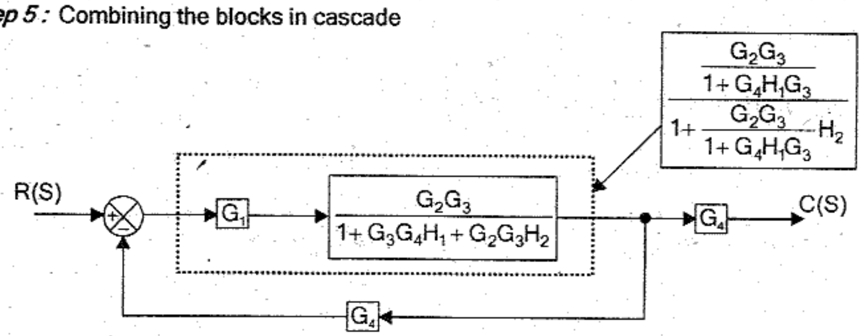
Step 3: Eliminating the feedback path



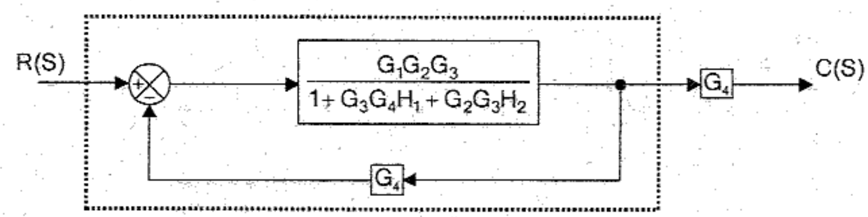
Step 4 : Combining the blocks in cascade and eliminating feedback path



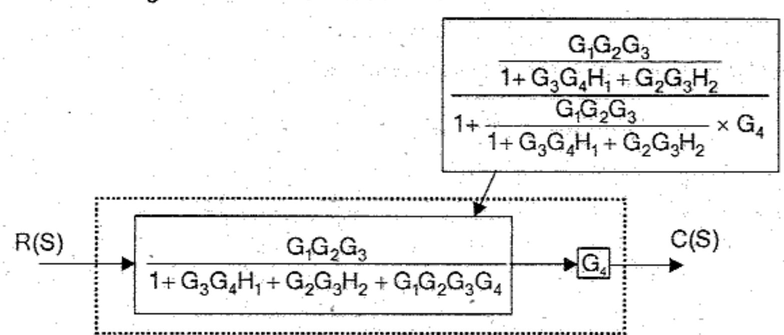
Step 5 : Combining the blocks in cascade



Step 6 : Eliminating the feedback path



Step 7 : Combining the blocks in cascade



$$\frac{C(s)}{R(s)} = \frac{G_1G_2G_3G_4}{1+G_3G_4H_1+G_2G_3H_2+G_1G_2G_3G_4}$$

ESULT

The overall transfer function of the system is given by,

$$\frac{C(s)}{R(s)} = \frac{G_1G_2G_3G_4}{1+G_3G_4H_1+G_2G_3H_2+G_1G_2G_3G_4}$$

TEMPERATURE CONTROL SYSTEM:

OPEN LOOP SYSTEM

The electric furnace shown in fig 1.3. is an open loop system. The output in the system is the desired temperature. The temperature of the system is raised by heat generated by the heating element. The output temperature depends on the time during which the supply to heater remains ON.

The ON and OFF of the supply is governed by the time setting of the relay. The temperature is measured by a sensor, which gives an analog voltage corresponding to the temperature of the furnace. The analog signal is converted to digital signal by an Analog - to - Digital converter (A/D converter).

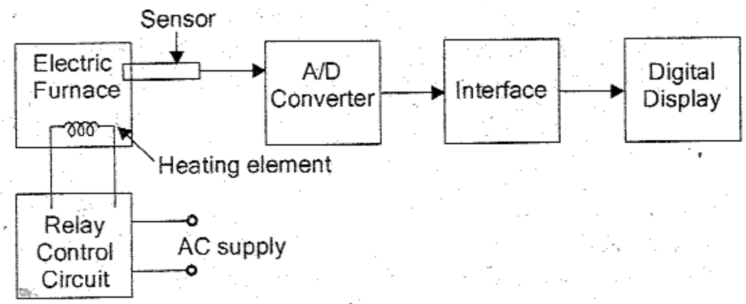


Fig 1.3 : Open loop temperature control system.

The digital signal is given to the digital display device to display the temperature. In this system if there is any change in output temperature then the time setting of the relay is not altered automatically.

CLOSED LOOP SYSTEM

The electric furnace shown in fig 1.4 is a closed loop system. The output of the system is the desired temperature and it depends on the time during which the supply to heater remains ON.

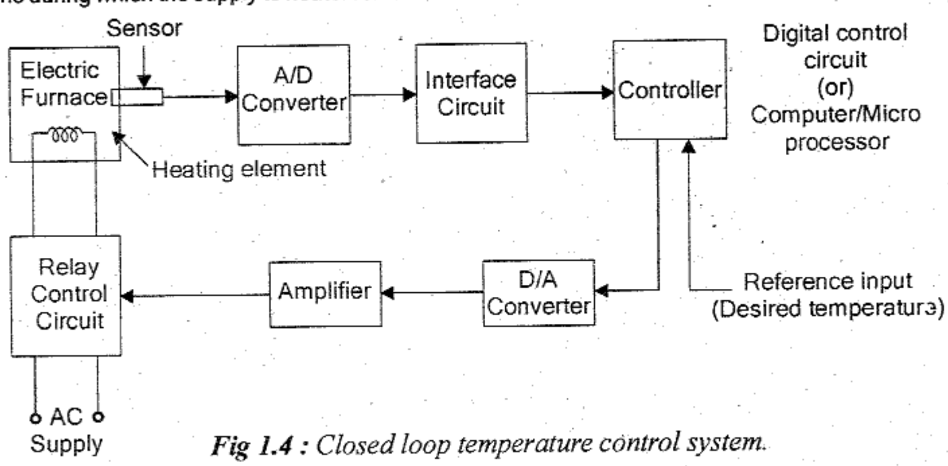


Fig 1.4 : Closed loop temperature control system.

The switching ON and OFF of the relay is controlled by a controller which is a digital system or computer. The desired temperature is input to the system through keyboard or as a signal corresponding to desired temperature via ports. The actual temperature is sensed by sensor and converted to digital signal by the A/D converter. The computer reads the actual temperature and compares with desired temperature. If it finds any difference then it sends signal to switch ON or OFF the relay through D/A converter and amplifier. Thus the system automatically corrects any changes in output. Hence it is a closed loop system.

EXAMPLE 3 : NUMERICAL CONTROL SYSTEM

OPEN LOOP SYSTEM

Numerical control is a method of controlling the motion of machine components using numbers. Here, the position of work head tool is controlled by the binary information contained in a disk.

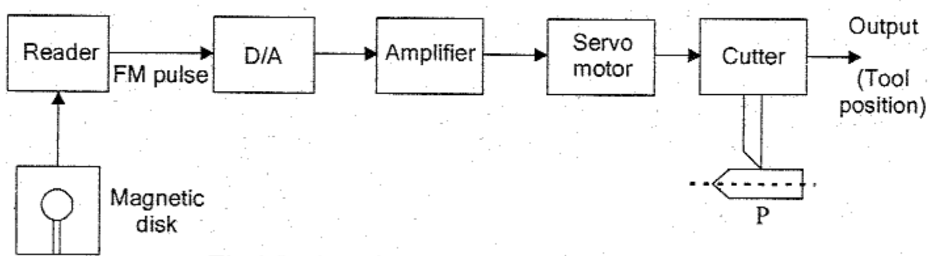


Fig 1.5 : Open loop numerical control system.

A magnetic disk is prepared in binary form representing the desired part P (P is the metal part to be machined). The tool will operate on the desired part P. To start the system, the disk is fed through the reader to the D/A converter. The D/A converter converts the FM(frequency modulated) output of the reader to a analog signal. It is amplified and fed to servometer which positions the cutter on the desired part P. The position of the cutter head is controlled by the angular motion of the servometer. This is an open loop system since no feedback path exists between the output and input. The system positions the tool for a given input command. Any deviation in the desired position is not checked and corrected automatically.

CLOSED LOOP SYSTEM

A magnetic disk is prepared in binary form representing the desired part P (P is the metal part to be machined). To start the system, the disk is loaded in the reader. The controller compares the frequency modulated input pulse signal with the feedback pulse signal. The controller is a computer or microprocessor system. The controller carries out mathematical operations on the difference in the pulse signals and generates an error signal. The D/A converter converts the controller output pulse (error signal) into an analog signal. The amplified analog signal rotates the servomotor to position the tool on the job. The position of the cutterhead is controlled according to the input of the servomotor.

The transducer attached to the cutterhead converts the motion into an electrical signal. The analog electrical signal is converted to the digital pulse signal by the A/D converter. Then this signal is compared with the input pulse signal. If there is any difference between these two, the controller sends a signal to the servomotor to reduce it. Thus the system automatically corrects any deviation in the desired output tool position. An advantage of numerical control is that complex parts can be produced with uniform tolerances at the maximum milling speed.

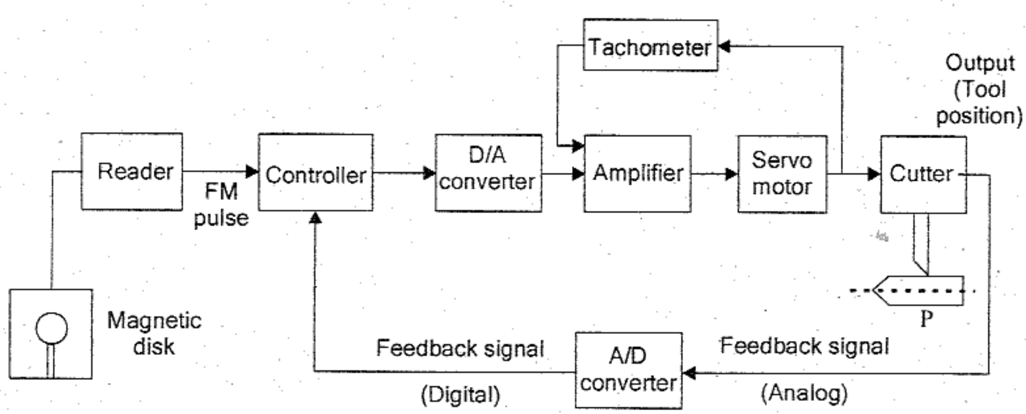


Fig 1.6 : Closed loop numerical control system.

2.6 RESPONSE OF FIRST ORDER SYSTEM FOR UNIT STEP INPUT

The closed loop order system with unity feedback is shown in fig 2.6.

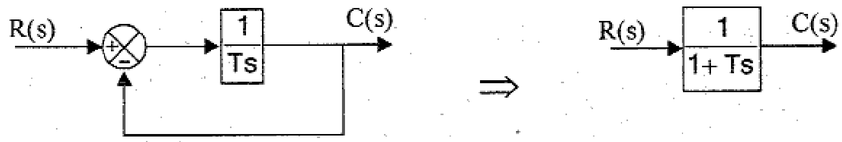


Fig 2.6 : *Closed loop for first order system.*

The closed loop transfer function of first order system, $\frac{C(s)}{R(s)} = \frac{1}{1+Ts}$

If the input is unit step then, $r(t) = 1$ and $R(s) = \frac{1}{s}$.

$$\therefore \text{The response in s-domain, } C(s) = R(s)\frac{1}{(1+Ts)} = \frac{1}{s}\frac{1}{(1+Ts)} = \frac{1}{sT\left(\frac{1}{T}+s\right)} = \frac{\frac{1}{T}}{s\left(s+\frac{1}{T}\right)}$$

By partial fraction expansion,

$$C(s) = \frac{\frac{1}{T}}{s\left(s+\frac{1}{T}\right)} = \frac{A}{s} + \frac{B}{\left(s+\frac{1}{T}\right)}$$

A is obtained by multiplying C(s) by s and letting s = 0.

$$A = C(s) \times s\Big|_{s=0} = \frac{\frac{1}{T}}{s\left(s+\frac{1}{T}\right)} \times s\Bigg|_{s=0} = \frac{\frac{1}{T}}{s+\frac{1}{T}}\Bigg|_{s=0} = \frac{\frac{1}{T}}{\frac{1}{T}} = 1$$

B is obtained by multiplying C(s) by (s+1/T) and letting s = –1/T.

$$B = C(s) \times \left(s+\frac{1}{T}\right)\Bigg|_{s=-\frac{1}{T}} = \frac{\frac{1}{T}}{s\left(s+\frac{1}{T}\right)} \times \left(s+\frac{1}{T}\right)\Bigg|_{s=-\frac{1}{T}} = \frac{\frac{1}{T}}{s}\Bigg|_{s=-\frac{1}{T}} = \frac{\frac{1}{T}}{\frac{-1}{T}} = -1$$

$$\therefore C(s) = \frac{1}{s} - \frac{1}{s+\frac{1}{T}}$$

$$\mathcal{L}\left\{e^{-at}\right\} = \frac{1}{s+a}$$

The response in time domain is given by,

$$c(t) = \mathcal{L}^{-1}\{C(s)\} = \mathcal{L}^{-1}\left\{\frac{1}{s} - \frac{1}{s+\frac{1}{T}}\right\} = 1 - e^{-\frac{t}{T}} \quad .....(2.13)$$

The equation (2.13) is the response of the closed loop first order system for unit step input. For step input of step value, A, the equation (2.13) is multiplied by A.

$\therefore$ For closed loop first order system, Unit step response $= 1 - e^{-\frac{t}{T}}$

Step response $= A\left(1 - e^{-\frac{t}{T}}\right)$

When, $t = 0$, $c(t) = 1 - e^{0} = 0$

When, $t = 1T$, $c(t) = 1 - e^{-1} = 0.632$

When, $t = 2T$, $c(t) = 1 - e^{-2} = 0.865$

When, $t = 3T$, $c(t) = 1 - e^{-3} = 0.95$

When, $t = 4T$, $c(t) = 1 - e^{-4} = 0.9817$

When, $t = 5T$, $c(t) = 1 - e^{-5} = 0.993$

When, $t = \infty$, $c(t) = 1 - e^{-\infty} = 1$

Here T is called Time constant of the system. In a time of 5T, the system is assumed to have attained steady state. The input and output signal of the first order system is shown in fig 2.7.

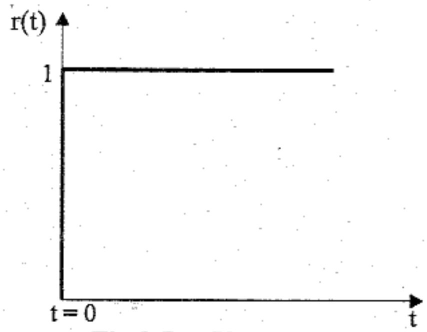


***Fig 2.7a** : Unit step input.*

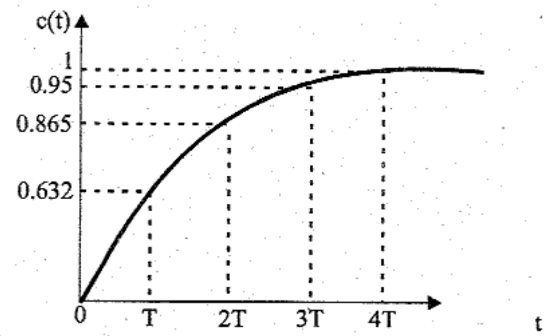


***Fig 2.7b** : Response for Unit step input.*

***Fig 2.7** : Response of first order system to Unit step input.*

2.7 SECOND ORDER SYSTEM

The closed loop second order system is shown in fig 2.8

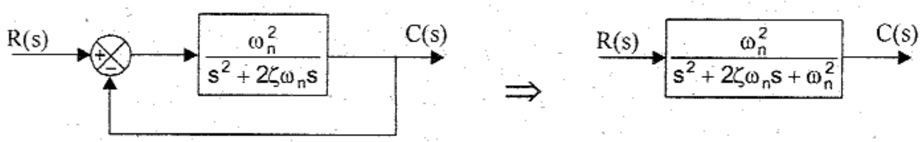


***Fig 2.8** : Closed loop for second order system.*

The standard form of closed loop transfer function of second order system is given by,

$$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} \qquad .....(2.14)$$

where, ω_n = Undamped natural frequency, rad/sec.

ζ = Damping ratio.

*The **damping ratio*** is defined as the ratio of the actual damping to the critical damping. The response c(t) of second order system depends on the value of damping ratio. Depending on the value of ζ, the system can be classified into the following four cases,

Case 1 : Undamped system, $\zeta = 0$

Case 2 : Under damped system, $0 < \zeta < 1$

Case 3 : Critically damped system, $\zeta = 1$

Case 4 : Over damped system, $\zeta > 1$

The characteristics equation of the second order system is,

$$s^2 + 2\zeta\omega_n s + \omega_n^2 = 0 \qquad .....(2.15)$$

It is a quadratic equation and the roots of this equation is given by,

$$s_1, s_2 = \frac{-2\zeta\omega_n \pm \sqrt{4\zeta^2\omega_n^2 - 4\omega_n^2}}{2} = \frac{-2\zeta\omega_n \pm \sqrt{4\omega_n^2(\zeta^2 - 1)}}{2}$$

$$= -\zeta\omega_n \pm \omega_n\sqrt{\zeta^2 - 1} \qquad .....(2.16)$$

When $\zeta = 0$, $s_1, s_2 = \pm j\omega_n$; $\begin{cases}\text{roots are purely imaginary} \\ \text{and the system is undamped}\end{cases}$ .....(2.17)

When $\zeta = 1$, $s_1, s_2 = -\omega_n$; $\begin{cases}\text{roots are real and equal and} \\ \text{the system is critically damped}\end{cases}$ .....(2.18)

When $\zeta > 1$, $s_1, s_2 = -\zeta\omega_n \pm \omega_n\sqrt{\zeta^2 - 1}$; $\begin{cases}\text{roots are real and unequal and} \\ \text{the system is overdamped}\end{cases}$ .....(2.19)

When $0 < \zeta < 1$, $s_1, s_2 = -\zeta\omega_n \pm \omega_n\sqrt{\zeta^2 - 1} = -\zeta\omega_n \pm \omega_n\sqrt{(-1)(1-\zeta^2)}$

$$= -\zeta\omega_n \pm \omega_n\sqrt{-1}\sqrt{1-\zeta^2} = -\zeta\omega_n \pm j\omega_n\sqrt{1-\zeta^2}$$

$$= -\zeta\omega_n \pm j\omega_d \; ; \begin{cases}\text{roots are complex conjugate} \\ \text{the system is underdamped}\end{cases} \quad .....(2.20)$$

$$\text{where, } \omega_d = \omega_n\sqrt{1-\zeta^2} \quad .....(2.21)$$

Here ω_d is called damped frequency of oscillation of the system and its unit is rad/sec.

2.7.1 RESPONSE OF UNDAMPED SECOND ORDER SYSTEM FOR UNIT STEP INPUT

The standard form of closed loop transfer function of second order system is,

$$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

For undamped system, z = 0.

$$\therefore \frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + \omega_n^2} \quad .....(2.22)$$

When the input is unit step, $r(t) = 1$ and $R(s) = \frac{1}{s}$.

$$\therefore \text{The response in s-domain, } C(s) = R(s)\frac{\omega_n^2}{s^2 + \omega_n^2} = \frac{1}{s}\frac{\omega_n^2}{s^2 + \omega_n^2} \quad .....(2.23)$$

By partial fraction expansion,

$$C(s) = \frac{\omega_n^2}{s(s^2 + \omega_n^2)} = \frac{A}{s} + \frac{B}{s^2 + \omega_n^2}$$

A is obtained by multiplying C(s) by s and letting s = 0.

$$A = C(s) \times s\Big|_{s=0} = \frac{\omega_n^2}{s(s^2 + \omega_n^2)} \times s\Bigg|_{s=0} = \frac{\omega_n^2}{s^2 + \omega_n^2}\Bigg|_{s=0} = \frac{\omega_n^2}{\omega_n^2} = 1$$

B is obtained by multiplying C(s) by $(s^2 + \omega_n^2)$ and letting $s^2 = -\omega_n^2$ or $s = j\omega_n$.

$$B = C(s) \times (s^2 + \omega_n^2)\Big|_{s=j\omega} = \frac{\omega_n^2}{s(s^2 + \omega_n^2)} \times (s^2 + \omega_n^2)\Bigg|_{s=j\omega} = \frac{\omega_n^2}{s}\Bigg|_{s=j\omega_n} = \frac{\omega_n^2}{j\omega_n} = -j\omega_n = -s$$

$$\therefore C(s) = \frac{A}{s} + \frac{B}{s^2 + \omega_n^2} = \frac{1}{s} - \frac{s}{s^2 + \omega_n^2}$$

$\mathcal{L}\{1\} = \frac{1}{s}$	$\mathcal{L}\{\cos \omega t\} = \frac{s}{s^2 + \omega^2}$

$$\text{Time domain response, } c(t) = \mathcal{L}^{-1}\{C(s)\} = \mathcal{L}^{-1}\left\{\frac{1}{s} - \frac{s}{s^2 + \omega_n^2}\right\} = 1 - \cos \omega_n t \quad .....(2.24)$$

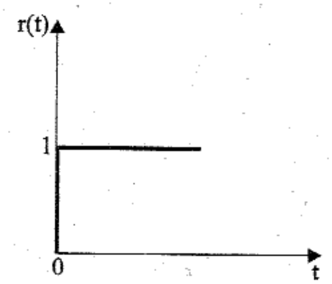


***Fig 2.9.a :** Input.*

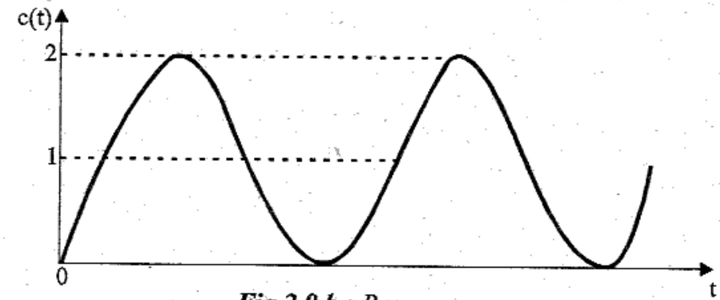


***Fig 2.9.b :** Response.*

***Fig 2.9 :** Response of undamped second order system for unit step input.*

Using equation (2.24), the response of undamped second order system for unit step input is sketched in fig 2.9, and observed that the response is completely oscillatory.

> ***Note :** Every practical system has some amount of damping. Hence undamped system does not exist in practice.*

The equation (2.24) is the response of undamped closed loop second order system for unit step input. For step input of step value A, the equation (2.24) should be multiplied by A.

> ∴ For closed loop undamped second order system,
>
> Unit step response $= 1 - \cos \omega_n t$
>
> Step response $= A(1 - \cos \omega_n t)$

Biocontrol System

UNIT-I

18BEBME501 BIO CONTROL SYSTEM

UNIT I INTRODUCTION TO BIO CONTROL SYSTEM (9)

Introduction: Technological control system, transfer function, mathematical approaches, system stability, introduction to biological control system, Modeling and block diagram, closed loop dynamics of first order and second order control system, similarities between biological and engineering control system, biological receptors and receptor characteristics

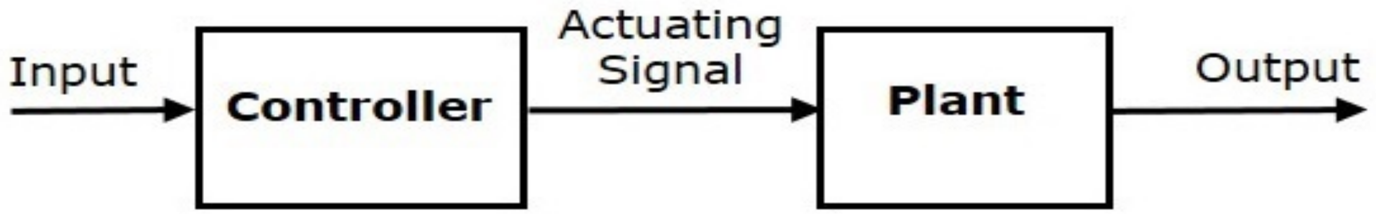
A control system is a system, which provides the desired response by controlling the output. The following figure shows the simple block diagram of a control system.

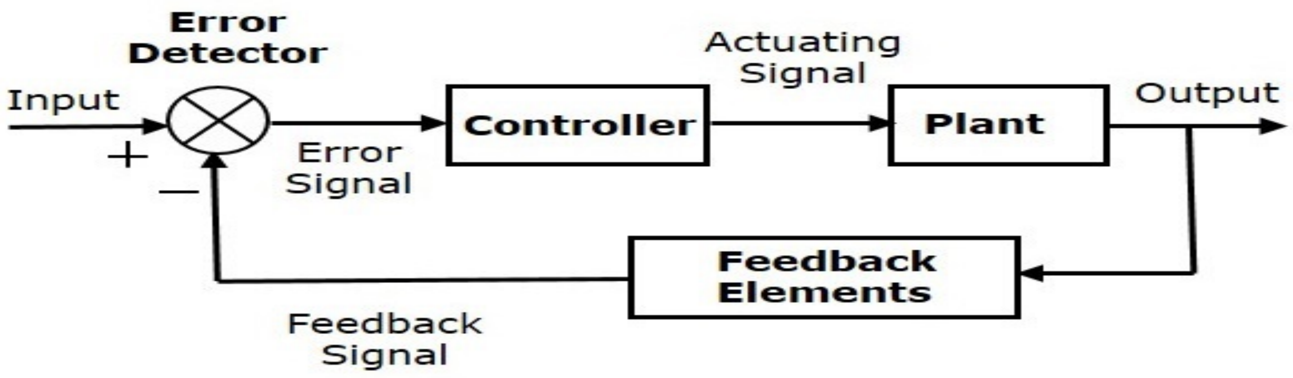
Here, the control system is represented by a single block. Since, the output is controlled by varying input, the control system got this name.
We will vary this input with some mechanism.
In the next section on open loop and closed loop control systems, we will study in detail about the blocks inside the control system and how to vary this input in order to get the desired response.

Examples − Traffic lights control system, washing machine

- Classification of Control Systems
- Based on some parameters, we can classify the control systems into the following ways.
- Continuous time and Discrete-time Control Systems
- Control Systems can be classified as continuous time control systems and discrete time control systems based on the **type of the signal** used.
- In **continuous time** control systems, all the signals are continuous in time. But, in **discrete time** control systems, there exists one or more discrete time signals.

- Open Loop and Closed Loop Control Systems
- Control Systems can be classified as open loop control systems and closed loop control systems based on the **feedback path**.
- In **open loop control systems**, output is not fed-back to the input. So, the control action is independent of the desired output.
- The following figure shows the block diagram of the open loop control system.



- Here, an input is applied to a controller and it produces an actuating signal or controlling signal. This signal is given as an input to a plant or process which is to be controlled. So, the plant produces an output, which is controlled. The traffic lights control system which we discussed earlier is an example of an open loop control system.
- In **closed loop control systems**, output is fed back to the input. So, the control action is dependent on the desired output.
- The following figure shows the block diagram of negative feedback closed loop control system.
- 

- The error detector produces an error signal, which is the difference between the input and the feedback signal. This feedback signal is obtained from the block (feedback elements) by considering the output of the overall system as an input to this block. Instead of the direct input, the error signal is applied as an input to a controller.
- So, the controller produces an actuating signal which controls the plant. In this combination, the output of the control system is adjusted automatically till we get the desired response. Hence, the closed loop control systems are also called the automatic control systems. Traffic lights control system having sensor at the input is an example of a closed loop control system.

The differences between the open loop and the closed loop control systems are mentioned in the following table.

Open Loop Control Systems	Closed Loop Control Systems
Control action is independent of the desired output.	Control action is dependent of the desired output.
Feedback path is not present.	Feedback path is present.
These are also called as **non-feedback control systems**.	These are also called as **feedback control systems**.
Easy to design.	Difficult to design.
These are economical.	These are costlier.
Inaccurate.	Accurate.

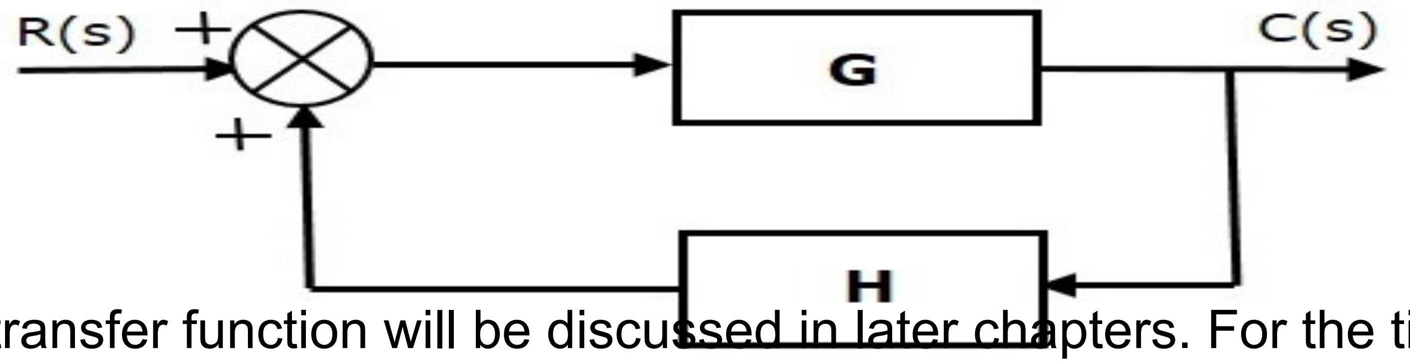
- If either the output or some part of the output is returned to the input side and utilized as part of the system input, then it is known as **feedback**.
- Feedback plays an important role in order to improve the performance of the control systems. In this chapter, let us discuss the types of feedback & effects of feedback.

There are two types of feedback −

- Positive feedback
- Negative feedback

Positive Feedback

The positive feedback adds the reference input, R(s)R(s) and feedback output. The following figure shows the block diagram of **positive feedback control system**.



The concept of transfer function will be discussed in later chapters. For the time being, consider the transfer function of positive feedback control system is,

$$T = \frac{G}{1-GH} \qquad \text{equation -----(1)}$$

Where,

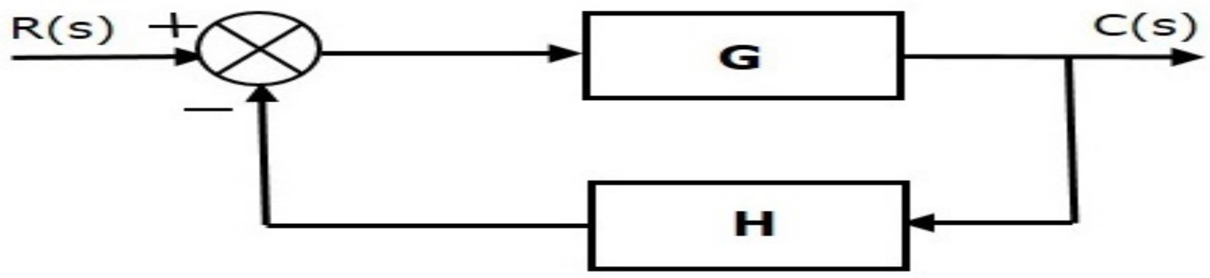
T is the transfer function or overall gain of positive feedback control system.

G is the open loop gain, which is function of frequency.

H is the gain of feedback path, which is function of frequency

Negative Feedback

Negative feedback reduces the error between the reference input, R(s)R(s) and system output. The following figure shows the block diagram of the **negative feedback control system**.



Transfer function of negative feedback control system is,

$$T = \frac{G}{1+GH}$$

Where,
T is the transfer function or overall gain of negative feedback control system.
G is the open loop gain, which is function of frequency.
H is the gain of feedback path, which is function of frequency.

- Effects of Feedback

Let us now understand the effects of feedback.

Effect of Feedback on Overall Gain From Equation 2,

From Equation 2, we can say that the overall gain of negative feedback closed loop control system is the ratio of 'G' and (1+GH). So, the overall gain may increase or decrease depending on the value of (1+GH).

If the value of (1+GH) is less than 1, then the overall gain increases. increases. In this case, 'GH' value is negative because the gain of the feedback path is negative.

- If the value of (1+GH) is greater than 1, then the overall gain decreases. decreases. In this case, 'GH' value is positive because the gain of the feedback path is positive.

- In general, general, 'G' and 'H' are functions of frequency. So, the feedback will increase the overall gain of the system in one frequency range and decrease in the other frequency range.

- Effect of Feedback on Sensitivity

- Sensitivity of the overall gain of negative negative feedback closed loop control control system (T) to the variation in open loop gain (G) is defined as

$$S = \frac{\partial T / T}{\partial G / G}$$

Sensitivity S = Percentage change in T / Percentage change in G

- $$S = \frac{1}{1+GH}$$

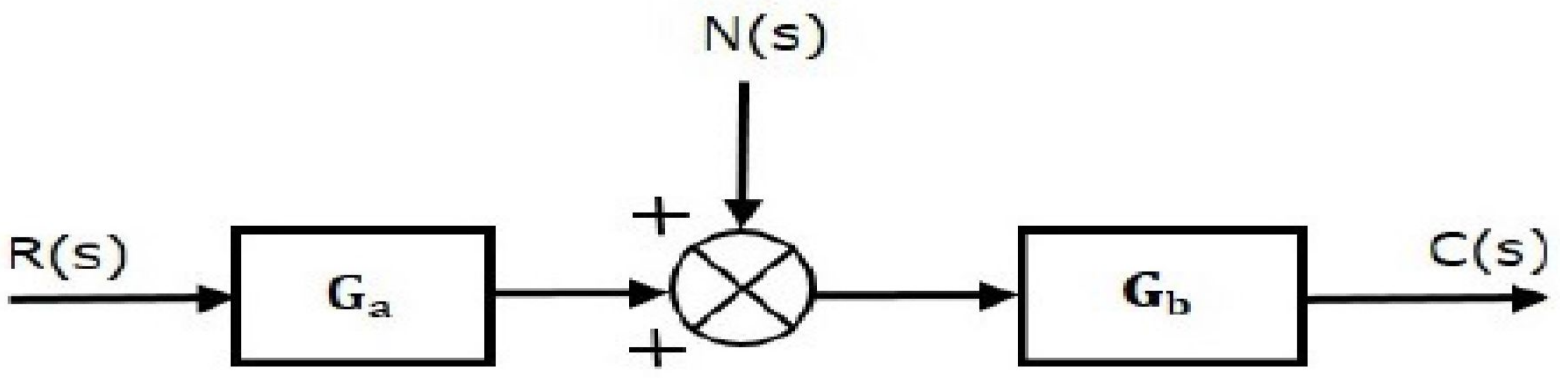
the sensitivity of the overall gain of closed loop control system as the reciprocal of (1+GH). So, Sensitivity may increase or decrease depending on the value of (1+GH).

- If the value of (1+GH) is less than 1, then sensitivity increases. increases. In this case, 'GH' value is negative because the gain of feedback path is negative.

- If the value of (1+GH) is greater than 1, then sensitivity decreases. decreases. In this case, 'GH' value is positive because the gain of feedback path is positive

- Effect of Feedback on Stability
- A system is said to be stable, stable, if its output is under control. control. Otherwise, Otherwise, it is said to be unstable. In Equation 2, if the denominator value is zero (i.e., GH = -1), then the output of the control system will be infinite.
- So, the control system becomes unstable.
- Therefore, we have to properly choose the feedback in order to make the control system stable.

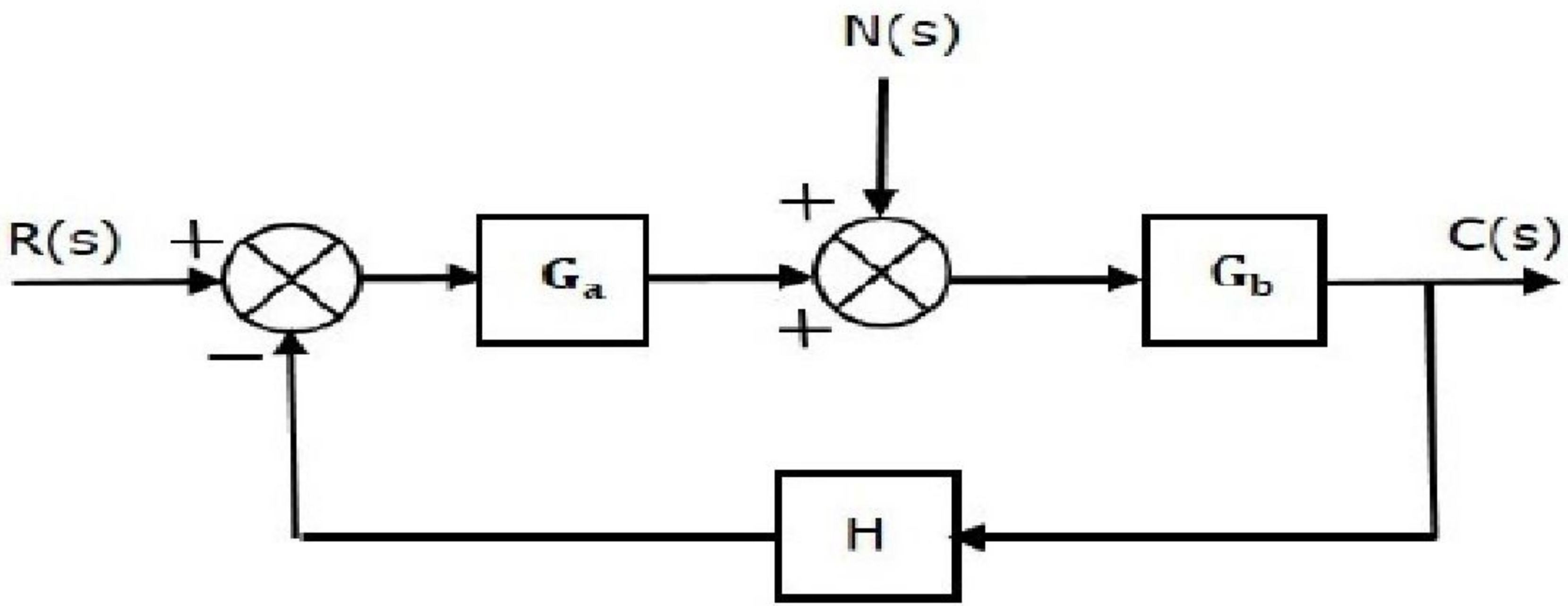
- Effect of Feedback on Noise
- To know the effect of feedback on noise, let us compare the transfer function relations with and without feedback due to noise signal alone.
- Consider an open loop control system with noise signal as shown below.



The **open loop transfer function** due to noise signal alone is

$$\frac{C(s)}{N(s)} = G_b \qquad \text{(Equation 7)}$$

Consider a **closed loop control system** with noise signal as shown below.



The **closed loop transfer function** due to noise signal alone is

$$\frac{C(s)}{N(s)} = \frac{G_b}{1+G_aG_bH} \qquad \text{(Equation 8)}$$

Mathematical model:

- The control systems can be represented with a set of mathematical equations known as **mathematical model**. These models are useful for analysis and design of control systems.
- Analysis of control system means finding the output when we know the input and mathematical model.
- Design of control system means finding the mathematical model when we know the input and the output.
- The following mathematical models are mostly used.
  - Differential equation model
  - Transfer function model
  - State space model

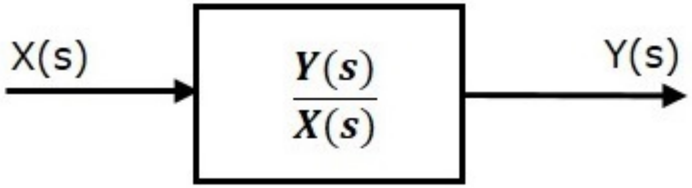
Transfer Function Model :

- Transfer function model is an s-domain mathematical model of control systems.
- The **Transfer function** of a Linear Time Invariant (LTI) system is defined as the ratio of Laplace transform of output and Laplace transform of input by assuming all the initial conditions are zero.

- If x(t) and y(t) are the input and output of an LTI system, then the corresponding Laplace transforms are X(s) and Y(s).
- Therefore, the transfer function of LTI system is equal to the ratio of Y(s) and X(s).

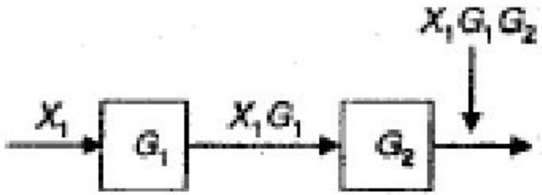
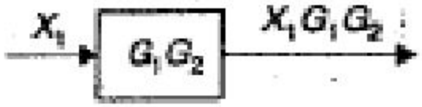
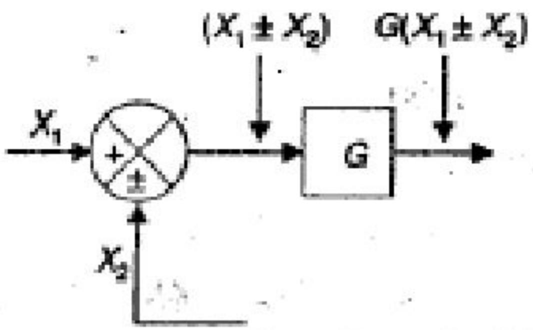
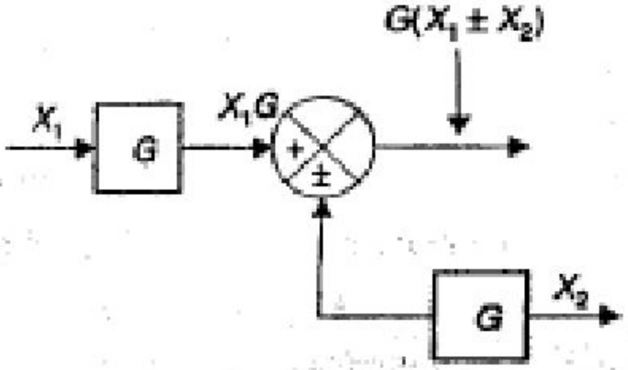
- Transfer function = Y(s) / X(s)

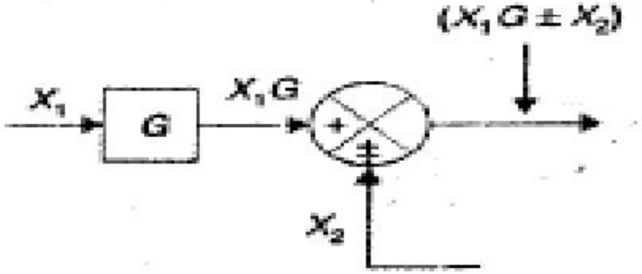
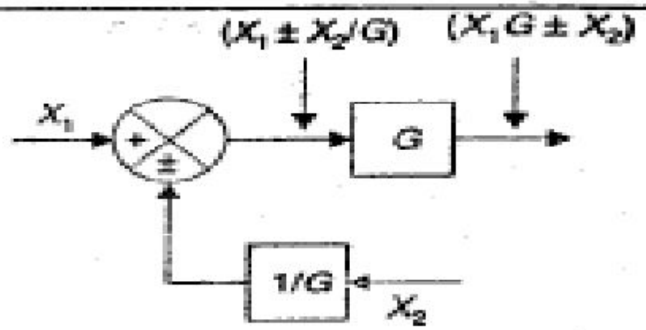
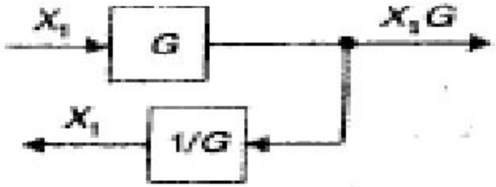
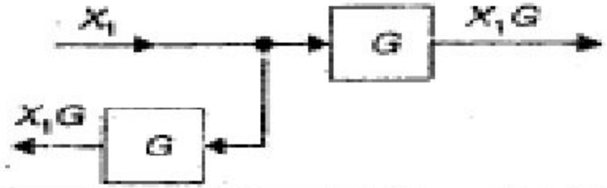
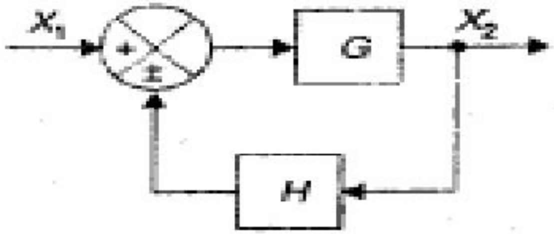
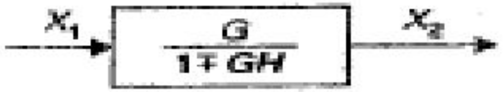
The transfer function model of an LTI system is shown in the following figure.



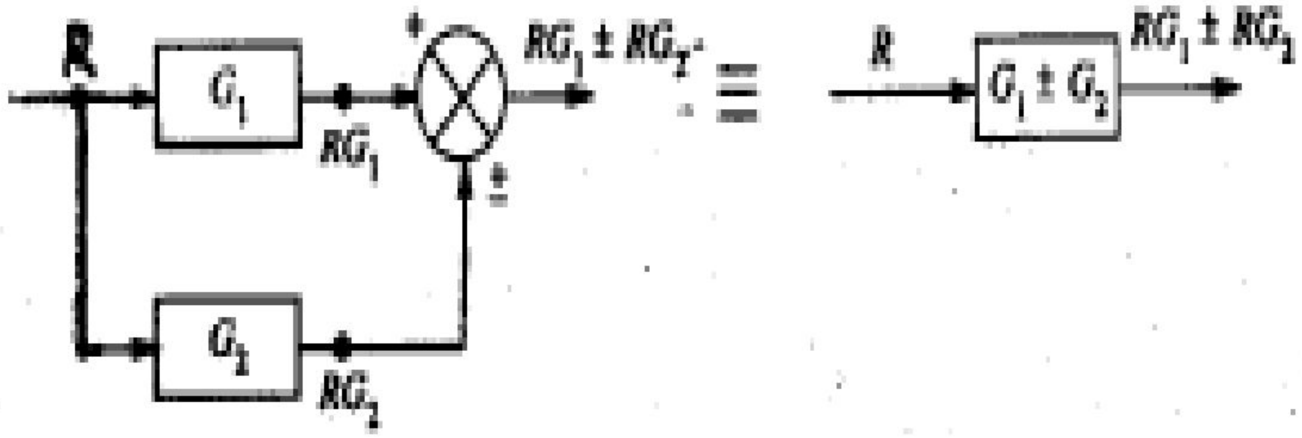
BLOCK DIAGRAM ALGEBRA

A complex system is represented by the interconnection of the blocks for individual elements. Evaluation of complex system requires simplification of block diagrams by block diagram rearrangement. Some of the important rules are given in figure below.

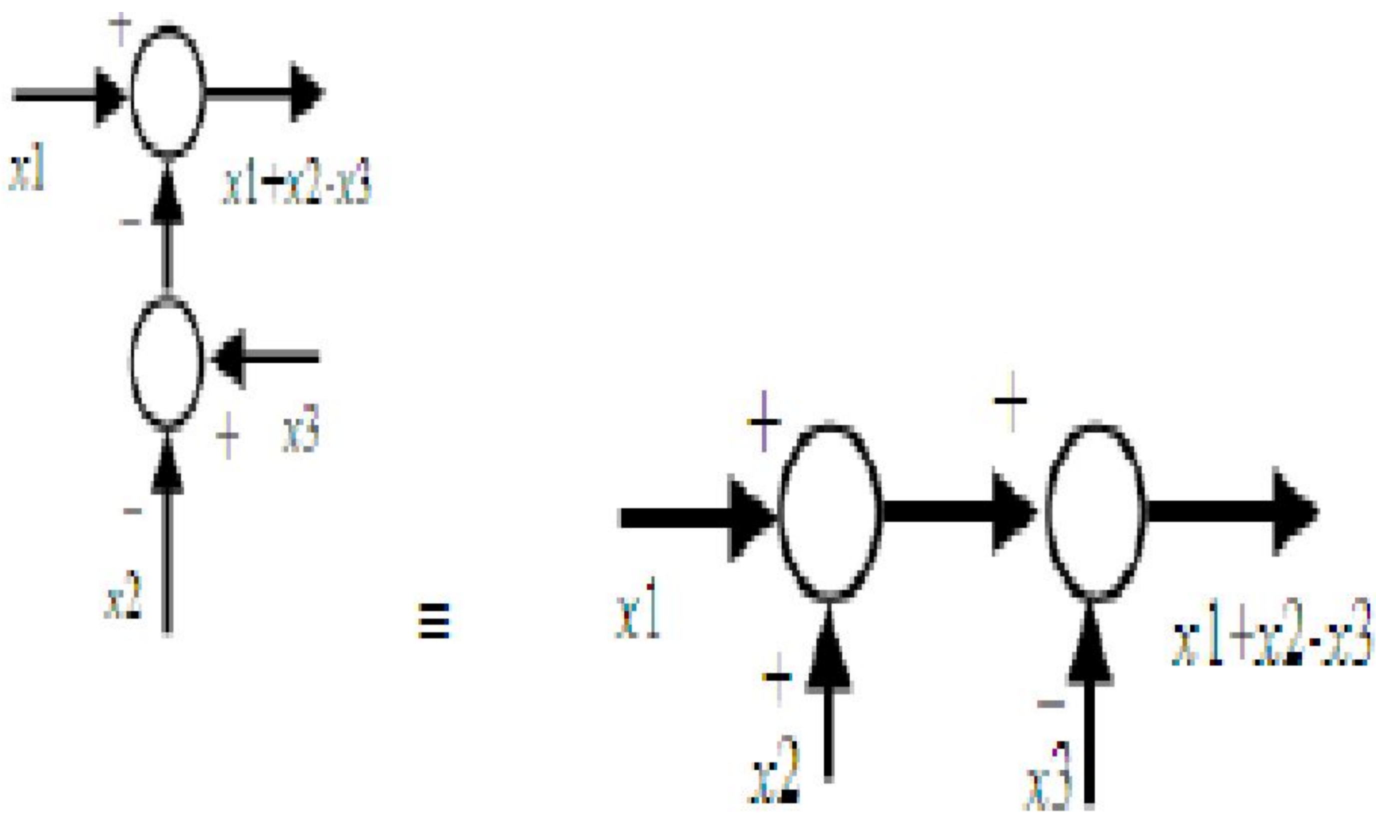
Rule	*Original diagram*	*Equivalent diagram*
1. Combining blocks in cascade		
2. Moving a summing point after a block		

3. **Moving a summing point ahead of a block**		
4. **Moving a take off point after a block**		
5. **Moving a take off point ahead of a block**		
6. **Eliminating a feedback loop**		

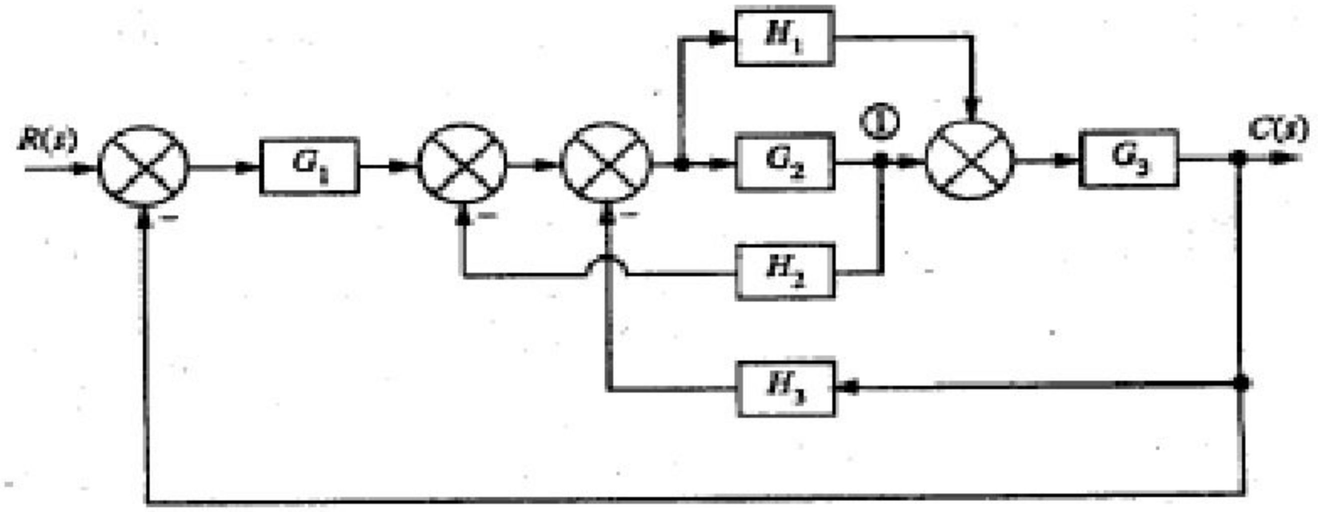
7. Combining Blocks in Parallel

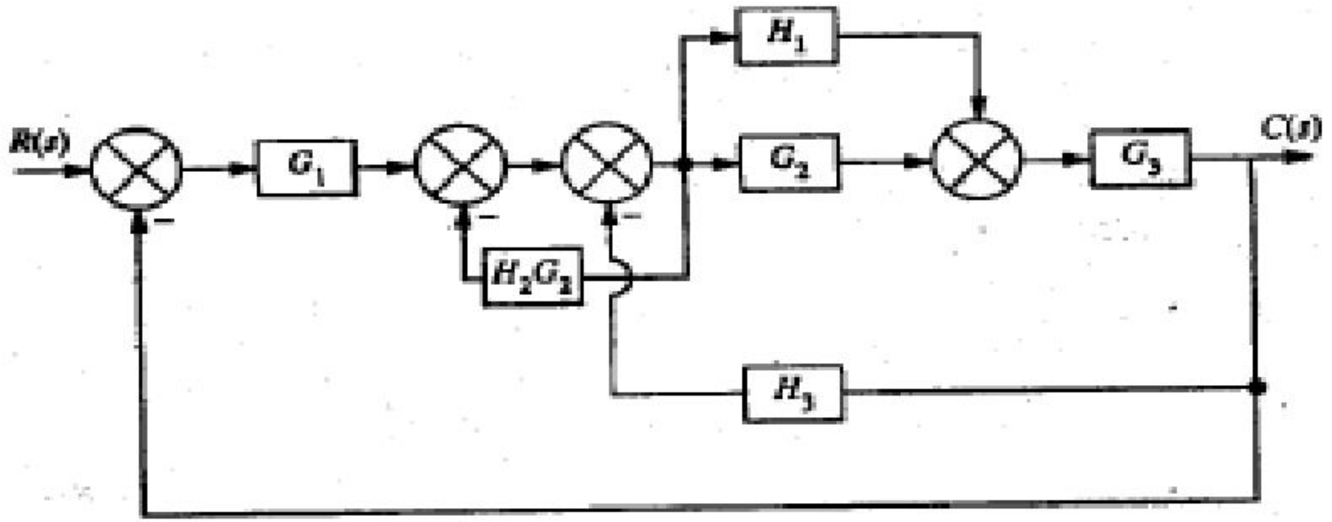


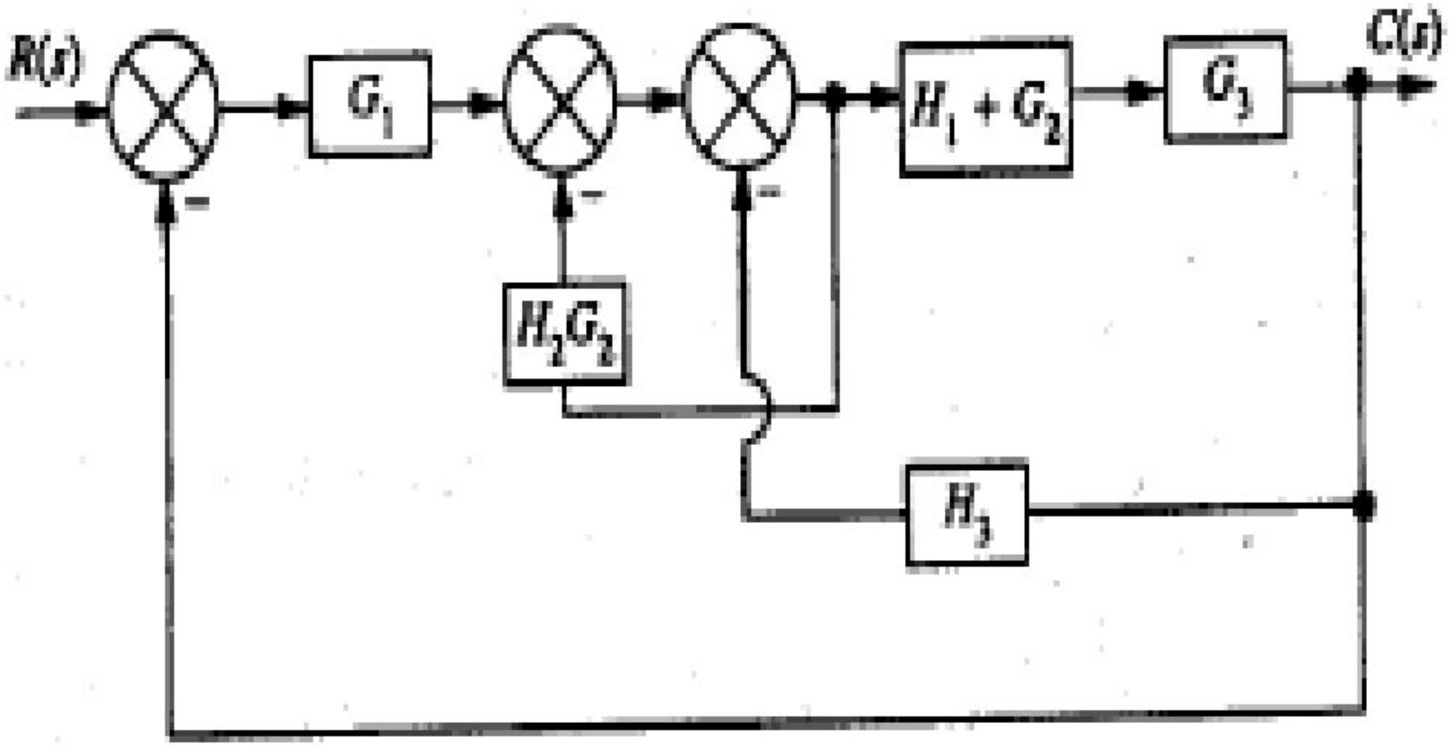
8. Moving summing point :



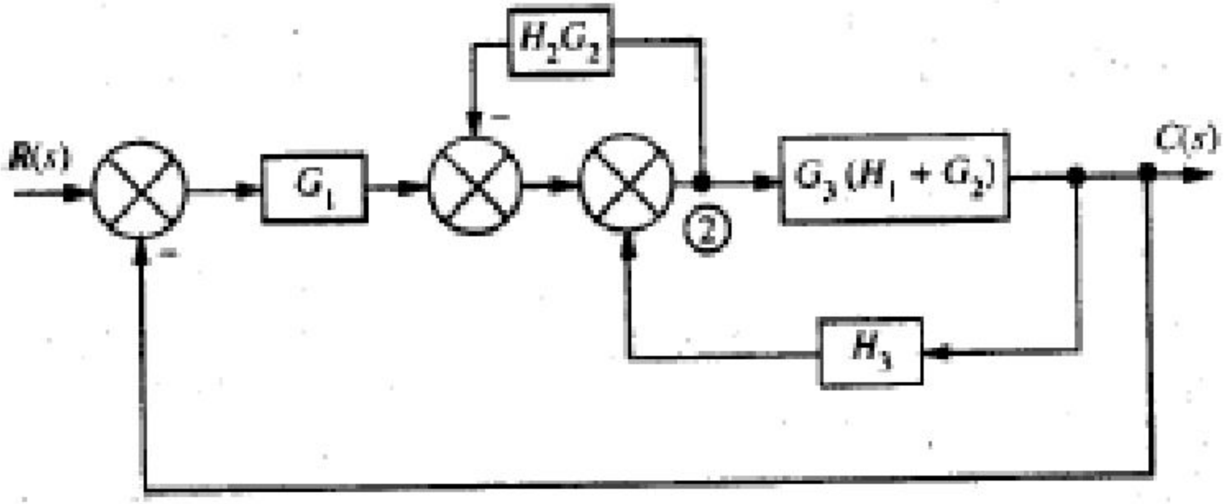
Example: Simplify the block diagram shown in Figure below.

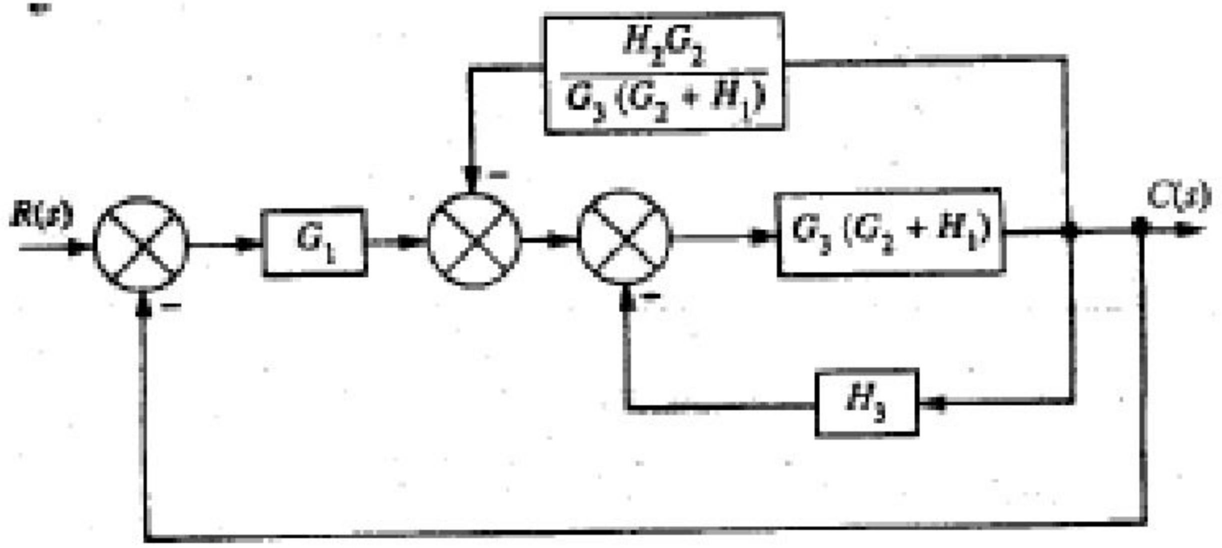


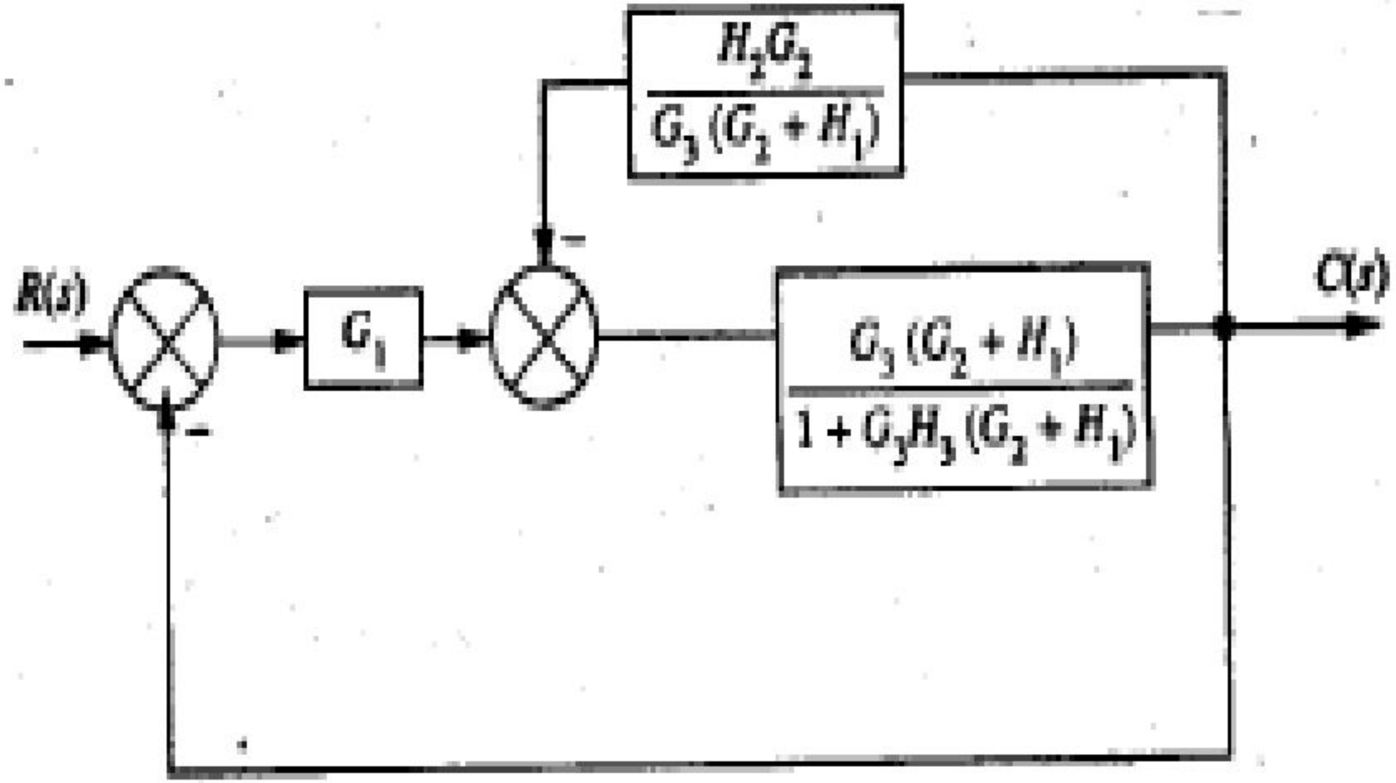




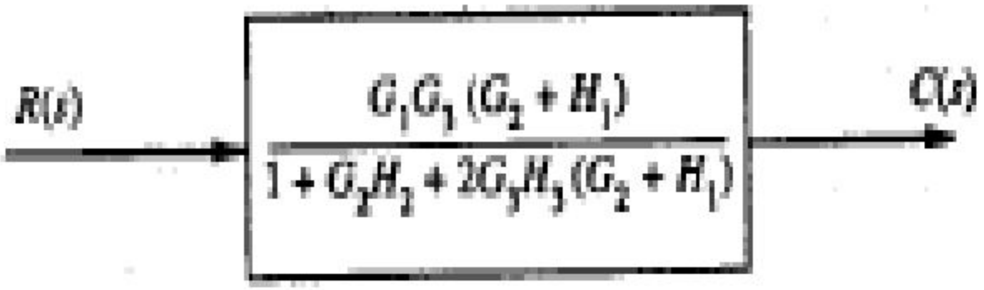
R(s)
G1
H1 + G2
G3
C(s)
H2G2
H3


R(s)
H2G2
G1
G3 (H1 + G2)
C(s)
2
H3


R(s)
H2G2
G3 (G2 + H1)
G1
G3 (G2 + H1)
C(s)
H3



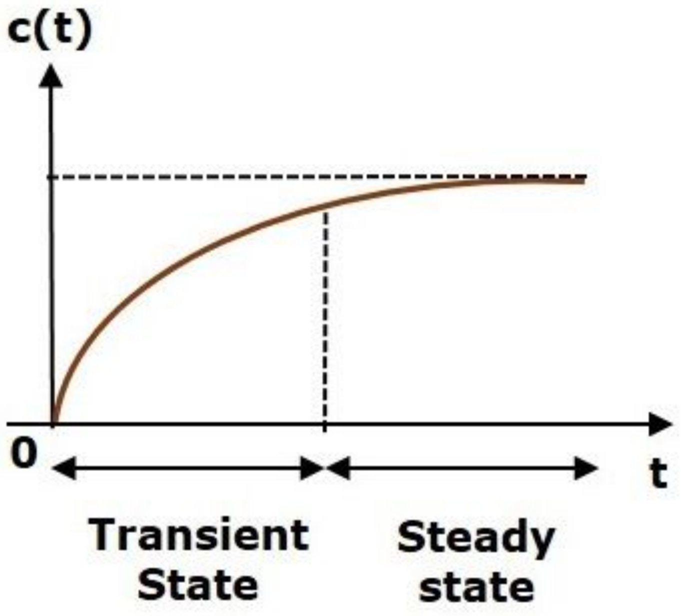
$\frac{H_2G_2}{G_3(G_2+H_1)}$
R(s)
G_1
$\frac{G_3(G_2+H_1)}{1+G_3H_3(G_2+H_1)}$
C(s)



R(s)
$\frac{G_1G_3(G_2+H_1)}{1+G_2H_2+2G_3H_3(G_2+H_1)}$
C(s)

Time response:

- If the output of control system for an input varies with respect to time, then it is called the **time response** of the control system. The time response consists of two parts.
- Transient response
- Steady state response
- The response of control system in time domain is shown in the following figure.



- The responses corresponding to these states are known as transient and steady state responses.

  Mathematically, we can write the time response c(t) as

$$c(t)=Ctr(t)+Css(t)$$

Where,

$c_{tr}(t)$ is the transient response, $c_{ss}(t)$ is the steady state response

Transient Response:

After applying input to the control system, output takes certain time to reach steady state. So, the output will be in transient state till it goes to a steady state. Therefore, the response of the control system during the transient state is known as **transient response**.

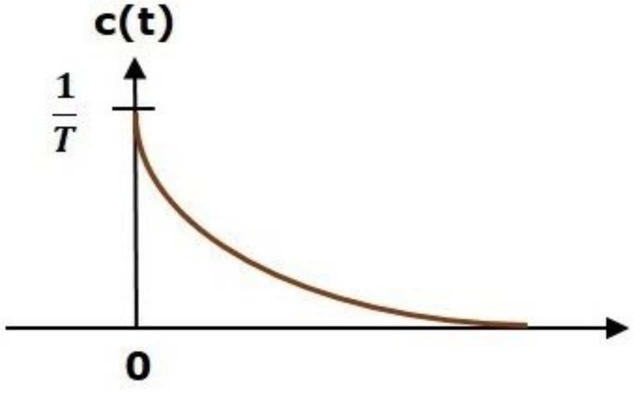
The transient response will be zero for large values of ‘t’. Ideally, this value of ‘t’ is infinity and practically, it is five times constant.

Mathematically, we can write it as,

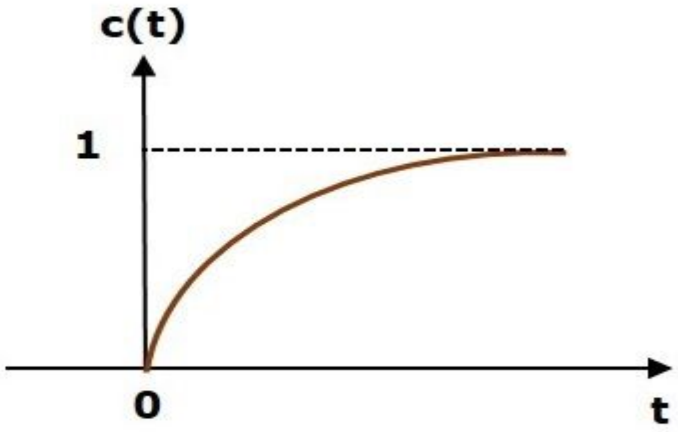
$$\lim_{t \to \infty} ctr(t)=0$$

Standard Test Signals:

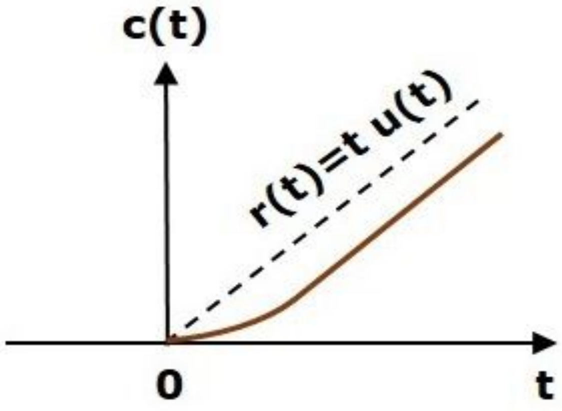
- The standard test signals are impulse, step, ramp and parabolic. These signals are used to know the performance of the control systems using time response of the output



a)Unit impulse



b)step



Closed loop dynamics of first order and second order control system:

- If the input is unit step, the output is step response. The step response yields a clear vision of the system’s transient response.

- We have two types of system, first order system and second order system, which are representative of many physical systems.

- First order of system is defined as first derivative with respect to time

- second order of system is second derivative with respect to time.

First Order Control System:

- The total response of the system is the sum of forced response and natural response

$$\text{Total response} = \text{Forced response} + \text{Natural response}$$

- The forced response is also called the steady state response or particular equation. The natural response is also called the homogeneous equation

Fundamental concepts of feedback control system:

- **Transfer Function**

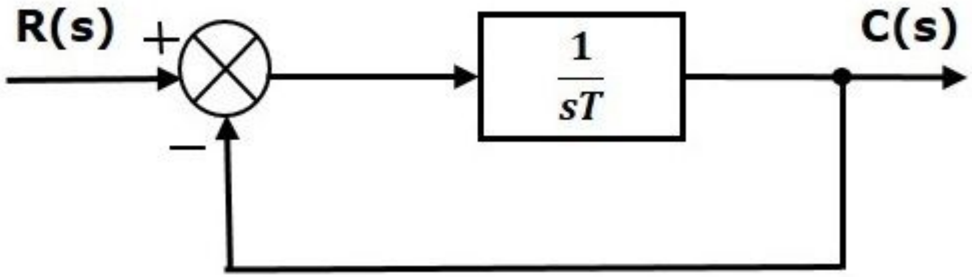
  It is defined as the ratio of output and input.

- **Poles of a Transfer Function**

  The poles of transfer function are the value of Laplace Transform variable(s), that cause the transfer function becomes infinite.

  The denominator of a transfer function is actually the poles of function.

- **Zeros of a Transfer Function**
- The zeros of transfer function are the values of Laplace Transform variable(s), that cause the transfer function becomes zero.
  The nominator of a transfer function is actually the zeros of function
- let us discuss the time response of the first order system. Consider the following block diagram of the closed loop control system. Here, an open loop transfer function, 1/sT is connected with a unity negative feedback.



The transfer function of the closed loop control system has unity negative feedback as,
$C(s)/ R(s)=G(s)/1+G(s)$

Substitute, $G(s)=1sTG(s)=1sT$ in the above equation.
$C(s)/R(s)=(1/sT)/1+(1/sT) \quad =1/(sT+1)$

- The power of s is one in the denominator term. Hence, the above transfer function is of the first order and the system is said to be the **first order system**.

We can re-write the above equation as

$$C(s)=(1/sT+1)R(s)$$

- Where,

C(s) is the Laplace transform of the output signal c(t),
R(s) is the Laplace transform of the input signal r(t), and
T is the time constant.

,

- **First order control system** tell us the speed of the response that what duration it reaches to the steady state.
- If the input is unit step, R(s) = 1/s so the output is step response C(s).

- The general equation of 1st order control system $C(s) = R(s)G(s)$ is $C(s) = a/s(s+a)\ and\ G(s)$ is transfer function.

- There are two poles, one is input pole at the origin s = 0 and other is system pole at s = -a

- Now taking the inverse transform so total response become $y(t) = c_f(t) + c_n(t)$

  Which is sum of forced response and natural response.

- Due to the input pole at the origin, produces the forced response as name describe by itself that giving forced to the system so it produces some response which is forced response

- And the system pole at -a produces natural response which is due to the transient response of the system.

2.7 SECOND ORDER SYSTEM

The closed loop second order system is shown in fig 2.8

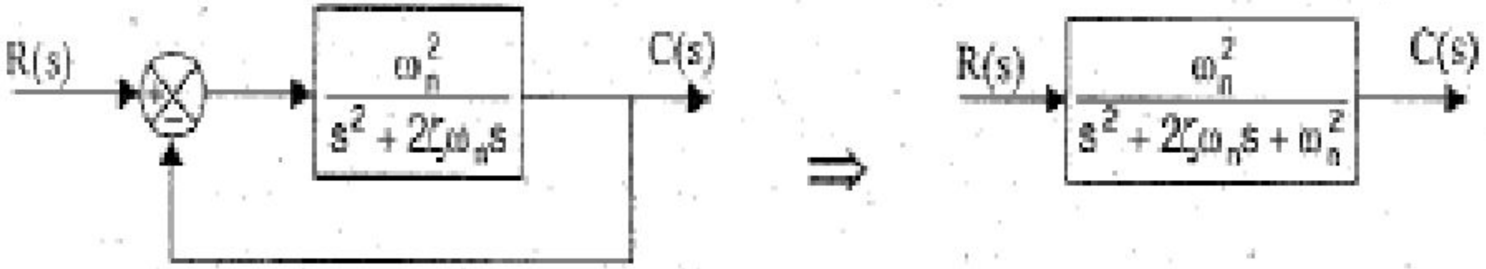


Fig 2.8 : Closed loop for second order system.

The standard form of closed loop transfer function of second order system is given by,

$$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} \qquad .....(2.14)$$

where, ω_n = Undamped natural frequency, rad/sec.

ζ = Damping ratio.

The ***damping ratio*** is defined as the ratio of the actual damping to the critical damping. The response c(t) of second order system depends on the value of damping ratio. Depending on the value of ζ, the system can be classified into the following four cases,

Case 1 : Undamped system, $\zeta = 0$

Case 2 : Under damped system, $0 < \zeta < 1$

Case 3 : Critically damped system, $\zeta = 1$

Case 4 : Over damped system, $\zeta > 1$

The characteristics equation of the second order system is,

$$s^2 + 2\zeta\omega_n s + \omega_n^2 = 0 \qquad .....(2.15)$$

It is a quadratic equation and the roots of this equation is given by,

$$s_1, s_2 = \frac{-2\zeta\omega_n \pm \sqrt{4\zeta^2\omega_n^2 - 4\omega_n^2}}{2} = \frac{-2\zeta\omega_n \pm \sqrt{4\omega_n^2(\zeta^2 - 1)}}{2}$$

$$= -\zeta\omega_n \pm \omega_n\sqrt{\zeta^2 - 1} \qquad .....(2.16)$$

When $\zeta = 0$, $s_1, s_2 = \pm j\omega_n$; $\begin{cases} \text{roots are purely imaginary} \\ \text{and the system is undamped} \end{cases}$ .....(2.17)

When $\zeta = 1$, $s_1, s_2 = -\omega_n$; $\begin{cases} \text{roots are real and equal and} \\ \text{the system is critically damped} \end{cases}$ .....(2.18)

When $\zeta > 1$, $s_1, s_2 = -\zeta\omega_n \pm \omega_n\sqrt{\zeta^2 - 1}$; $\begin{cases} \text{roots are real and unequal and} \\ \text{the system is overdamped} \end{cases}$ .....(2.19)

When $0 < \zeta < 1$, $s_1, s_2 = -\zeta\omega_n \pm \omega_n\sqrt{\zeta^2 - 1} = -\zeta\omega_n \pm \omega_n\sqrt{(-1)\,(1-\zeta^2)}$

$$= -\zeta\omega_n \pm \omega_n\sqrt{-1}\,\sqrt{1-\zeta^2} = -\zeta\omega_n \pm j\omega_n\sqrt{1-\zeta^2}$$

$$= -\zeta\omega_n \pm j\omega_d\,;\ \begin{cases} \text{roots are complex conjugate} \\ \text{the system is underdamped} \end{cases} \quad .....(2.20)$$

$$\text{where, } \omega_d = \omega_n\sqrt{1-\zeta^2} \quad .....(2.21)$$

Here ω_d is called damped frequency of oscillation of the system and its unit is rad/sec.

2.7.1 RESPONSE OF UNDAMPED SECOND ORDER SYSTEM FOR UNIT STEP INPUT

The standard form of closed loop transfer function of second order system is,

$$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

For undamped system, z = 0.

$$\therefore \frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + \omega_n^2} \quad \text{.....(2.22)}$$

When the input is unit step, $r(t) = 1$ and $R(s) = \frac{1}{s}$.

$$\therefore \text{The response in s-domain, } C(s) = R(s)\,\frac{\omega_n^2}{s^2 + \omega_n^2} = \frac{1}{s}\,\frac{\omega_n^2}{s^2 + \omega_n^2} \quad \text{.....(2.23)}$$

By partial fraction expansion,

$$C(s) = \frac{\omega_n^2}{s\,(s^2 + \omega_n^2)} = \frac{A}{s} + \frac{B}{s^2 + \omega_n^2}$$

A is obtained by multiplying C(s) by s and letting s = 0.

$$A = C(s) \times s\Big|_{s=0} = \frac{\omega_n^2}{s\,(s^2+\omega_n^2)} \times s\Bigg|_{s=0} = \frac{\omega_n^2}{s^2+\omega_n^2}\Bigg|_{s=0} = \frac{\omega_n^2}{\omega_n^2} = 1$$

B is obtained by multiplying C(s) by $(s^2 + \omega_n^2)$ and letting $s^2 = -\omega_n^2$ or $s = j\omega_n$.

$$B = C(s) \times (s^2+\omega_n^2)\Big|_{s=j\omega} = \frac{\omega_n^2}{s\,(s^2+\omega_n^2)} \times (s^2+\omega_n^2)\Bigg|_{s=j\omega} = \frac{\omega_n^2}{s}\Bigg|_{s=j\omega_n} = \frac{\omega_n^2}{j\omega_n} = -j\omega_n = -s$$

$$\therefore\ C(s) = \frac{A}{s} + \frac{B}{s^2+\omega_n^2} = \frac{1}{s} - \frac{s}{s^2+\omega_n^2}$$

$\mathcal{L}\{1\} = \frac{1}{s}$	$\mathcal{L}\{\cos \omega t\} = \frac{s}{s^2+\omega^2}$

Time domain response, $c(t) = \mathcal{L}^{-1}\{C(s)\} = \mathcal{L}^{-1}\left\{\frac{1}{s} - \frac{s}{s^2+\omega_n^2}\right\} = 1 - \cos \omega_n t$ .....(2.24)

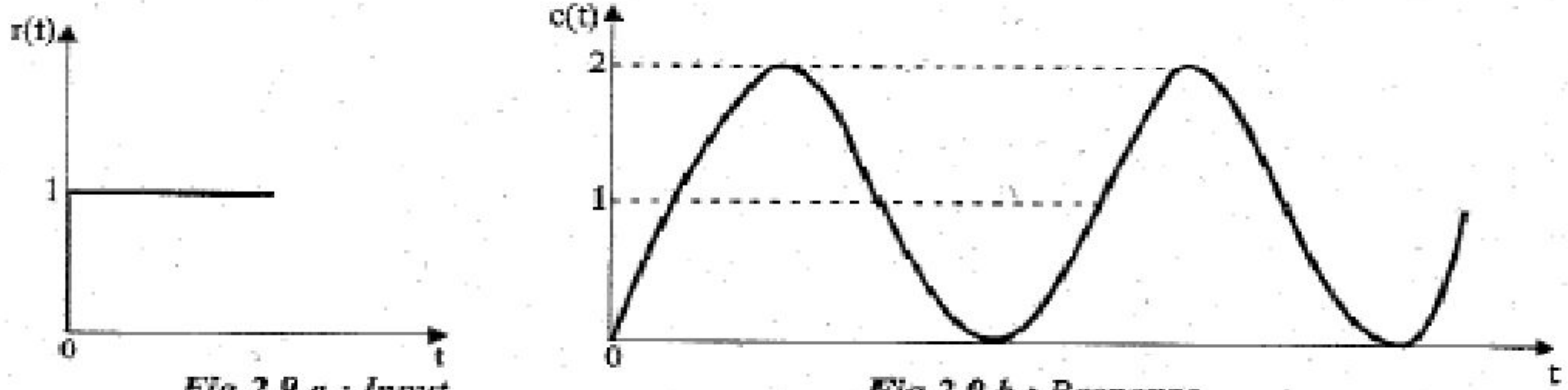


Fig 2.9.a : Input.

Fig 2.9.b : Response.

***Fig 2.9 :** Response of undamped second order system for unit step input.*

Using equation (2.24), the response of undamped second order system for unit step input is sketched in fig 2.9, and observed that the response is completely oscillatory.

> ***Note :** Every practical system has some amount of damping. Hence undamped system does not exist in practice.*

The equation (2.24) is the response of undamped closed loop second order system for unit step input. For step input of step value A, the equation (2.24) should be multiplied by A.

∴ For closed loop undamped second order system,

Unit step response $= 1 - \cos \omega_n t$

Step response $= A(1 - \cos \omega_n t)$

TEMPERATURE CONTROL SYSTEM:

OPEN LOOP SYSTEM

The electric furnace shown in fig 1.3. is an open loop system. The output in the system is the desired temperature. The temperature of the system is raised by heat generated by the heating element. The output temperature depends on the time during which the supply to heater remains ON.

The ON and OFF of the supply is governed by the time setting of the relay. The temperature is measured by a sensor, which gives an analog voltage corresponding to the temperature of the furnace. The analog signal is converted to digital signal by an Analog - to - Digital converter (A/D converter).

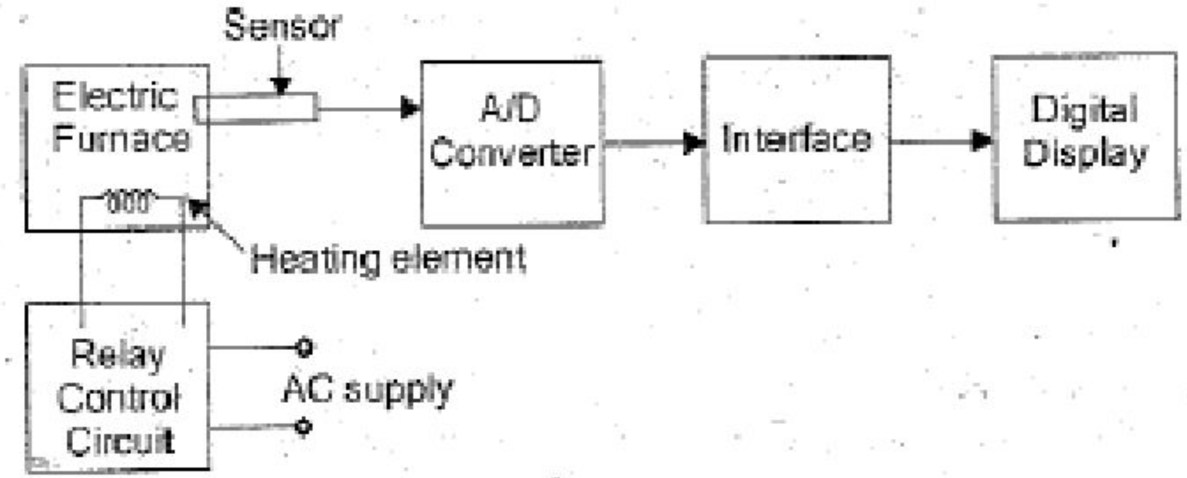


Fig 1.3 : Open loop temperature control system.

The digital signal is given to the digital display device to display the temperature. In this system if there is any change in output temperature then the time setting of the relay is not altered automatically.

CLOSED LOOP SYSTEM

The electric furnace shown in fig 1.4 is a closed loop system. The output of the system is the desired temperature and it depends on the time during which the supply to heater remains ON.

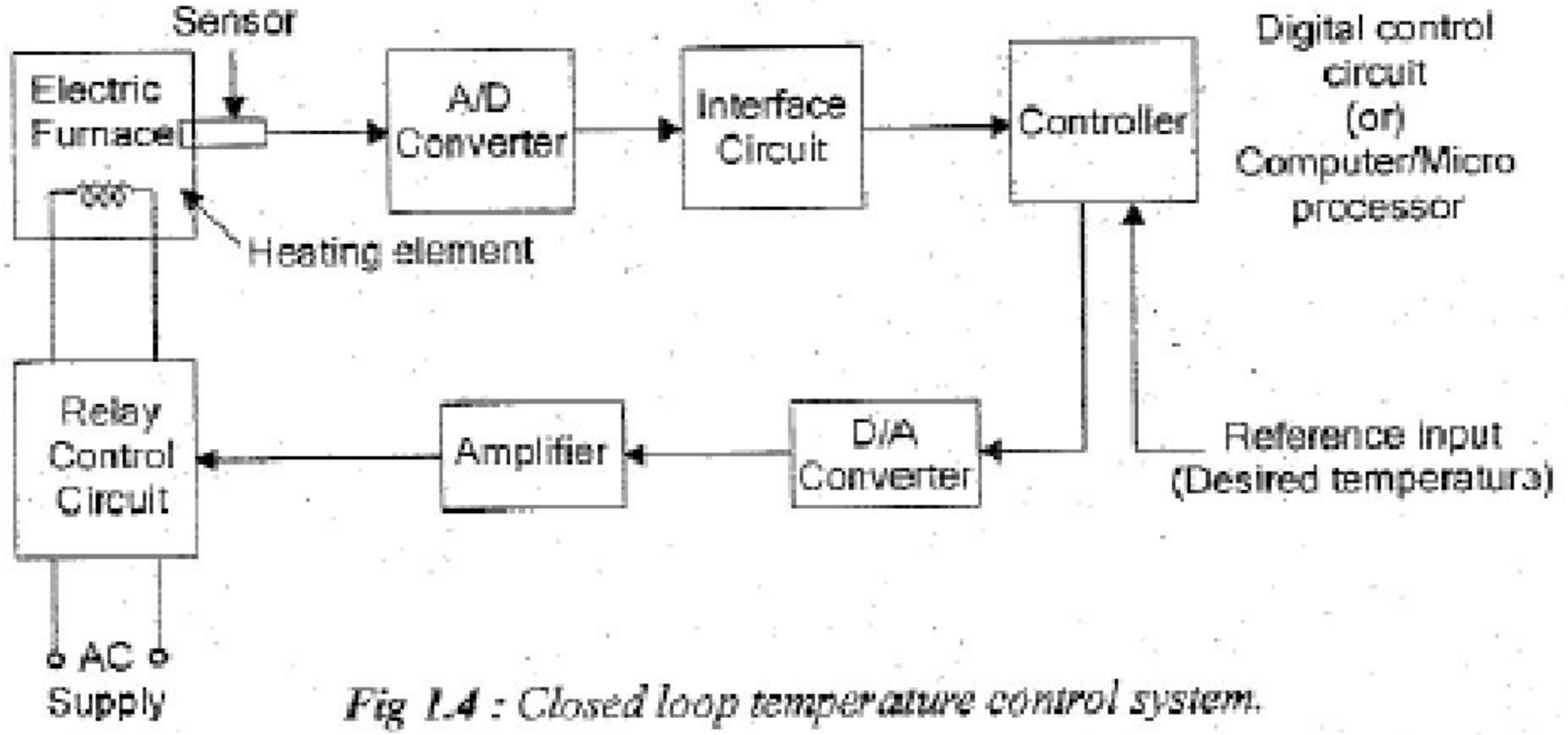


Fig 1.4 : Closed loop temperature control system.

The switching ON and OFF of the relay is controlled by a controller which is a digital system or computer. The desired temperature is input to the system through keyboard or as a signal corresponding to desired temperature via ports. The actual temperature is sensed by sensor and converted to digital signal by the A/D converter. The computer reads the actual temperature and compares with desired temperature. If it finds any difference then it sends signal to switch ON or OFF the relay through D/A converter and amplifier. Thus the system automatically corrects any changes in output. Hence it is a closed loop system.

Simple Physiological Examples Of Open Loop & Closed Loop

- Thermo regulatory control in *Poikilothermic* animals.
- Cold Blooded Animals thermo control is an open loop control while it is a closed loop control in the warm blooded animals (homeothermic)
- Homeostasis i.e, Maintenance of the relatively constant physiological conditions

Differences between the Physiological and Engineering control system

- An engineering control system is designed to accomplish a given task
  - Physiological systems are versatile and capable of serving different functions
- Engineering control has components that are generally known to the designer
  - Physiological control systems usually consists of components that are unknown and difficult to analyze

Differences between the Physiological and Engineering control system

- Physiological systems are adaptive

- Physiological systems have an extensive degree of cross coupling

The Design Process

- Building a model for the plant to be controlled
- Writing the mathematical equations describing the system
- Develop a controller to control the system according to the specifications given
- Testing and analysis (both in time domain and frequency domain)

Components of Biological Control systems

Receptors :-

- Behaviour in all its forms & shapes has definitely a biological or physiological base.
- The behaviour is based on the various stimuli present in the external environment & lying within our body.

the stimuli in the form of various

sensory experiences are received by our

sensory system known as Receptors.

External Receptors :-

- External receptors are those sensory mechanisms that helps us make contact with the outer world. fo eg: eyes, ears, nose, tongue & skin.

- The specific receptors cells for receiving the external stimuli lie within this sensory stem.

• All receptors exhibit general characteris-tics.

1.) Specific Binding : (Structural and steric specificity).

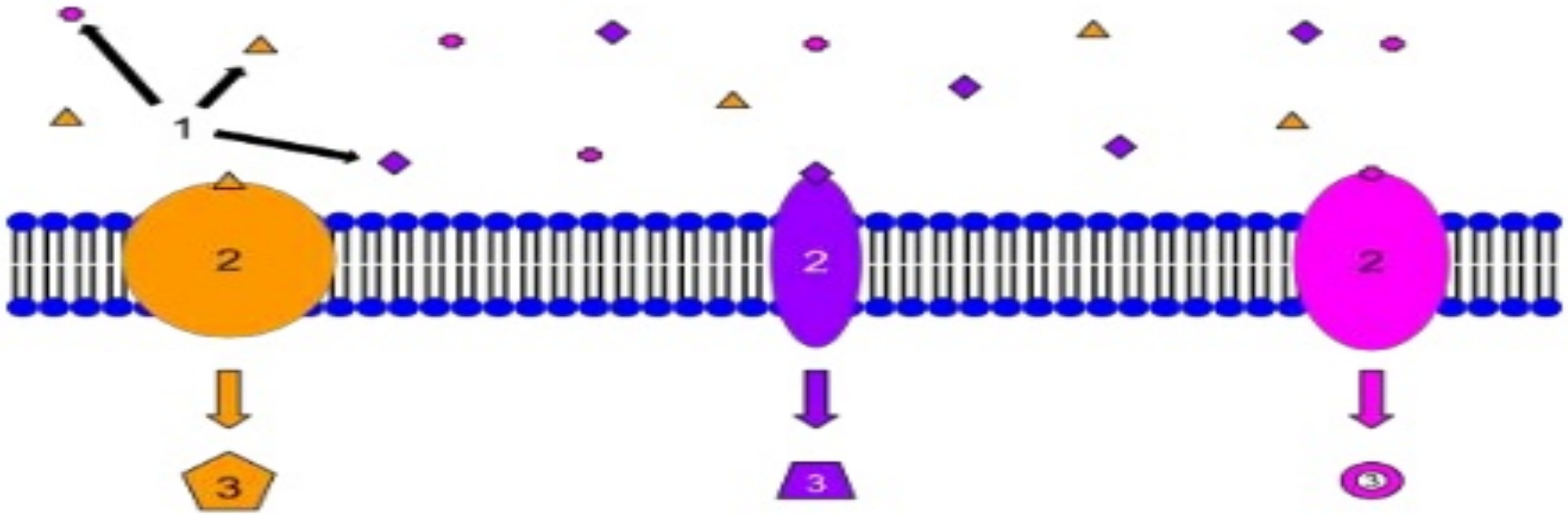
2.) High affinity (at physiological concentration).

3.) saturation (limited, finite no. of binding site).

4.) signal ~~tr~~ Transduction (only when

Receptor

A receptor is a protein molecule usually found embedded within the plasma membrane surface of a cell that receives chemical signals from outside the cell and when such chemical signals bind to a receptor, they cause some form of cellular/tissue response.



Classification

There are 2 types of receptors. Those are : **Internal** & **Cell surface receptor**.

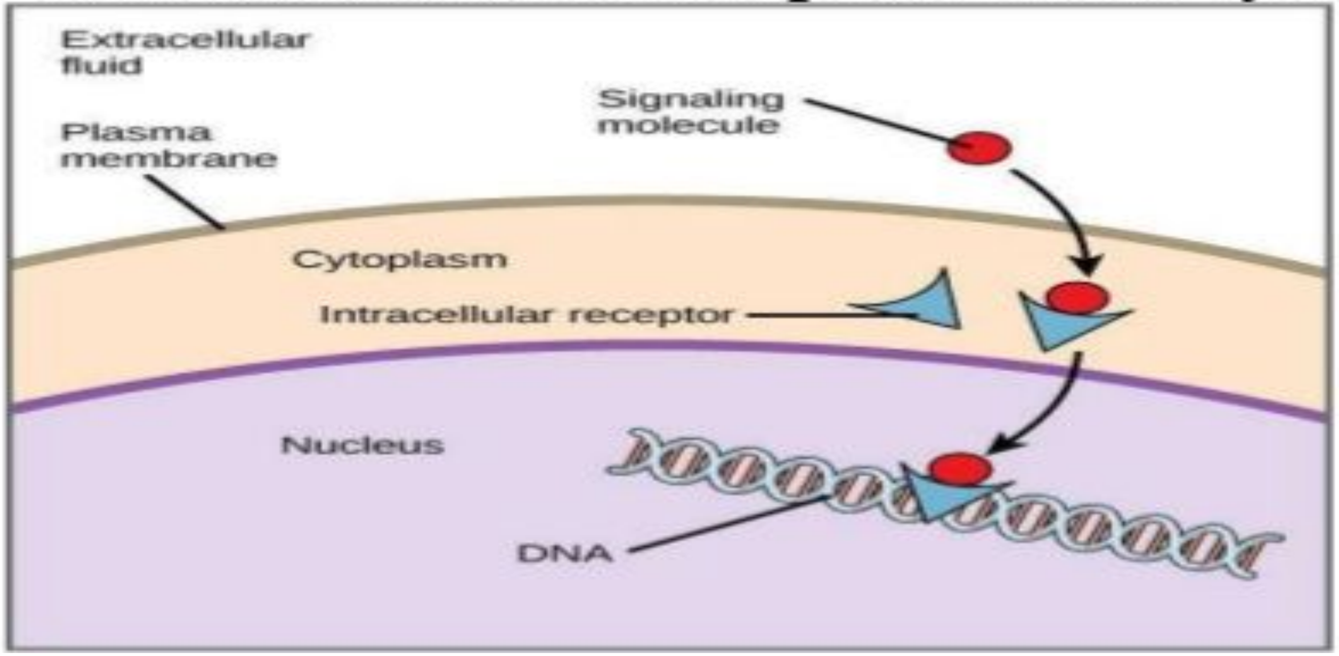
i. **Internal /Intracellular/Cytoplasmic receptors** :

- ✓ found in the cytoplasm of the cell
- ✓ respond to hydrophobic ligand molecules

Internal receptor :

Intracellular Receptors :

- ✓Hydrophobic signaling molecules typically diffuse across the plasma membrane
- ✓interact with intracellular receptors in the cytoplasm.



Cell surface receptor

ii. **Cell-surface /transmembrane receptors/cell-specific proteins**

- ✓ performs signal transduction, converting an extracellular signal into an intracellular signal.

3 main components:

i. an external ligand-binding domain (extracellular domain),
ii. a hydrophobic membrane-spanning region,
iii. and an intracellular domain inside the cell.

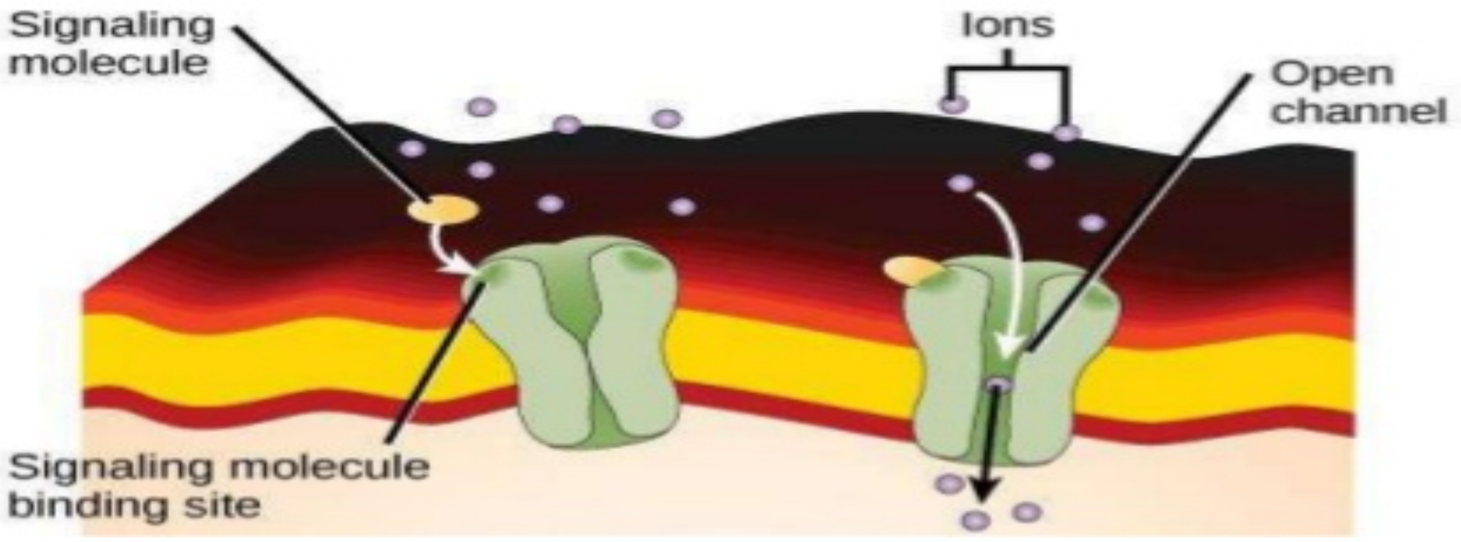
Cell surface receptor

There are three general categories of cell-surface receptors:

1. Ion channel-linked receptors,
2. G-protein-linked receptors,
3. Enzyme-linked receptors.

Ion Channel-Linked Receptors

- Receptors bind with ligand. (Ex:**Nicotinic Receptor**)
- Open a channel through the membrane that allows specific ions to pass through.
- Conformational change in the protein's structure that allows ions such as Na,Ca, Mg, and H_2 to pass through.

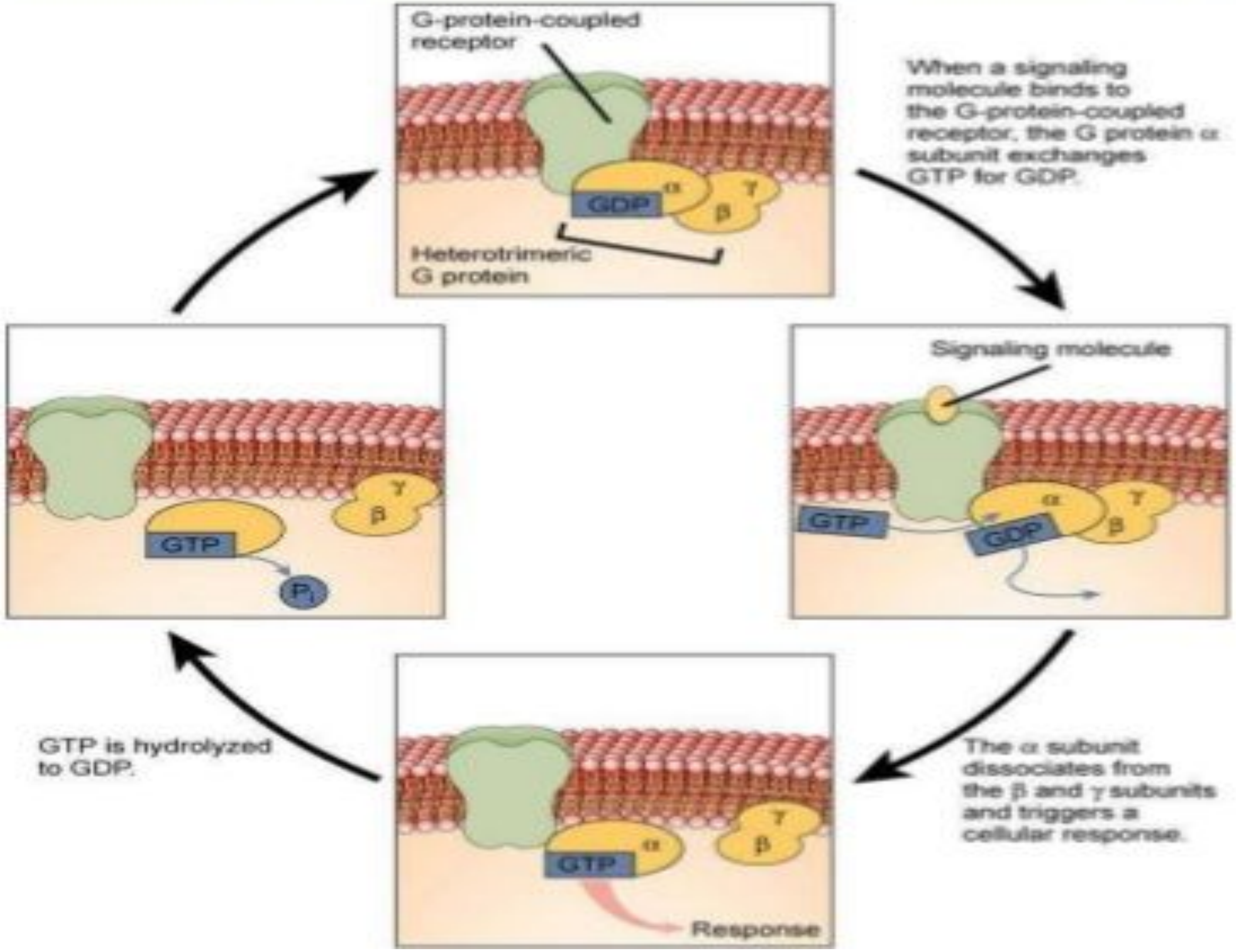


G-Protein Linked Receptors

- ✓ Binds with a ligand and activate a membrane protein called a G-protein.
- ✓ The activated G-protein then interacts with either an ion channel or an enzyme in the membrane.
- ✓ Each receptor has its own specific extracellular domain and G-protein-binding site.

Example : **Beta-adrenergic receptor**

G-Protein Linked Receptors



Enzyme-Linked Receptors

- ✓Cell surface receptors with intracellular domains that are associated with an enzyme.
- ✓ Normally have large extracellular and intracellular domains.
- ✓When a ligand binds to the extracellular domain, a signal is transferred through the membrane and activates the enzyme, which eventually leads to a response.

Example : **Tyrosine Kinase receptor**

INTERSTITIAL FLUID:

Interstitial fluid are the body **fluid** between blood vessels and cells., containing nutrients from capillary by diffusion and holding waste products discharged out by cells due to metabolism. Eleven litres of the ECF is **interstitial fluid** and the remaining three litres is plasma. Interstitial fluid consists of a water solvent containing sugars, salts, fatty acids, amino acids, coenzymes, hormones, neurotransmitters, white blood cells and cell waste-products. This solution accounts for 26% of the water in the human body.

EXTRA CELLULAR WATER:

Extracellular fluid (**ECF**) denotes all body fluid outside the cells of any multicellular organism. Total body water in healthy adults is about 60% (range 45 to 75%) of total body weight; women and the obese have a lower percentage than lean men. About two thirds of this is intracellular fluid within cells, and one third is the extracellular fluid.[1] The main component of the extracellular fluid is the **interstitial fluid** that surrounds cells. Extracellular fluid is the internal environment of all multicellular animals, and in those animals with a blood circulatory system a proportion of this fluid is blood plasma.

BLOOD PRESSURE:

The blood pressure is defined as the lateral pressure exerted by the flowing blood on the wall of the vessels. It is also called systemic arterial pressure(SAP). BP is generated mainly due to pumping of blood by the heart into the less complaint and always full arterial system. So, the pressure will be more during systole and less during diastole of the heart. These are called:

1) Systolic blood pressure
2) Diastolic blood pressure

HOMEOSTATSIS:

Homeostasis is the ability or tendency to maintain internal stability in an organism to compensate for environmental changes. **Homeostatic** regulation involves **three** parts or mechanisms:

1) the receptor,

2) the control center and

3) the effector.

The ***receptor*** receives information that something in the environment is changing. The ***control center*** or ***integration center*** receives and processes information from the ***receptor***. And lastly, the ***effector*** responds to the commands of the ***control center*** by either opposing or enhancing the stimulus.

BLOOD GLUCOSE POOL:

The fast or accessible plasma pool describes tissues such as the brain, which requires a constant rate of glucose uptake independent of insulin. The other component of the fast pool is the ability of glucose to stimulate its own uptake (diffusion) independent of insulin (i.e., liver).

ACID BASE BALANCE REGULATION:

Acid- base homeostasis concerns proper balance between acid and base. It is also called body pH. When the body pH is not maintained properly, proteins are not digested, cell metabolism are collapsed, enzymes loss their ability to function. Body functions normally only when body pH goes to neutral. The normal value of pH range is between 7.35- 7.45 deviation outside their range is a dangerous one. To maintain this acid-base balance two systems are involved in our body.

1) Respiration systems
2) Urinary systems

The relation between pH and hydrogen ion is

$$pH = -\log H^+$$

or

$$pH = \log\left(\frac{1}{H}\right)$$

CASE:1 When pH less than 7.35 (acidity increases)

Increase in acidity is called acidosis. When pH level decreases it stimulates the chemoreceptor and arterial receptors so that respiration rate in the lungs get increases, the respiratory systems alters the respiratory rate to change the concentration of CO2 in the blood (decreased CO2). The chemical reaction of CO2 and water is

$$CO_2 + H_2 0 \rightarrow H^+ + HCO_3^-$$

Blood CO2 decreases and hydrogen ions also decrease as per the relationship of H+ ions and pH. pH increases, H+ ions decreases. This process is restored at equilibrium conditions.

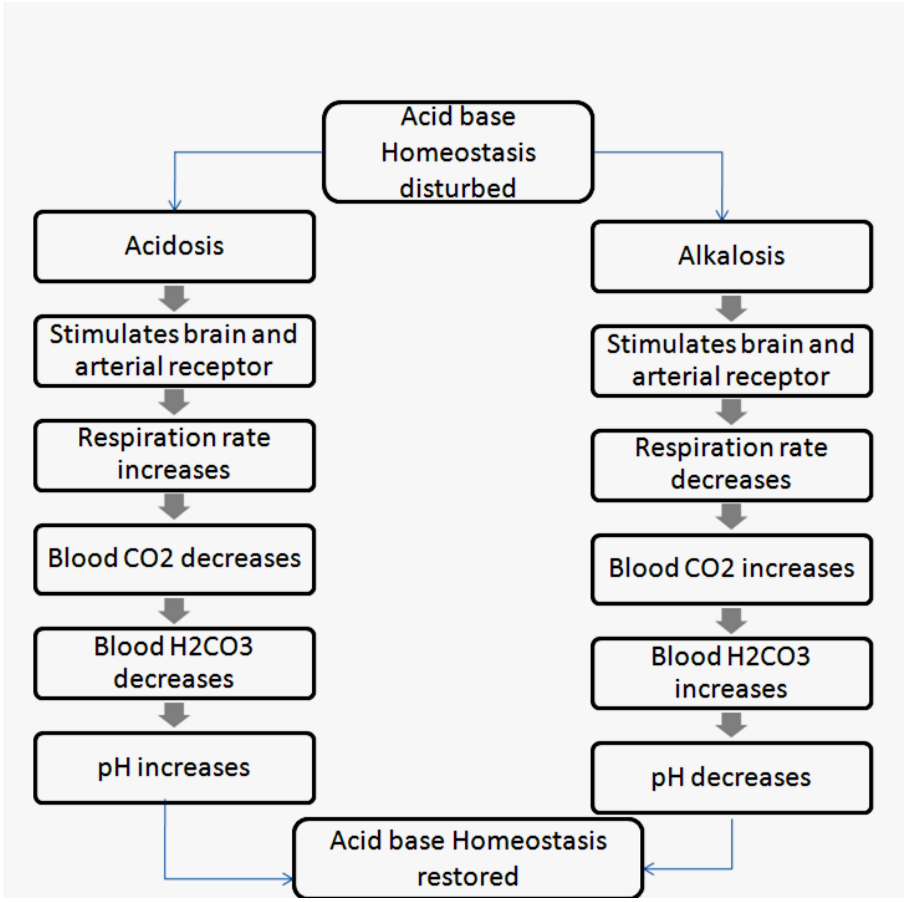
CASE:1 When pH greater than 7.35 (acidity decreases)

Decrease in acidity is called alkalosis. When pH level increases, it stimulates the chemoreceptor and arterial receptors so that the respiration rate in the lungs gets decreases, the respiratory system alters the respiration rate to change the concentration of CO2 in the blood (increased CO2).

The chemical reaction of CO2 and water is

$$CO_2 + H_2 0 \rightarrow H^- + HCO_3^+$$

Blood CO2 decreases and H+ increases as per the relationship of H+ ions and pH. pH decreases, H+ ions increases. Acid- base homeostasis is restored.



EXPLAINATION:

The respiratory system contributes to the balance of acids and bases in the body by regulating the blood levels of carbonic acid.

CO_2 in the blood readily reacts with water to form carbonic acid, and the levels of CO_2 and carbonic acid in the blood are in equilibrium.

When the CO_2 level in the blood rises (when we hold the breath) the excess CO_2 reacts with water to form additional carbonic acid, lowering blood pH.

Increasing the rate and/or depth of respiration allows us to exhale more CO_2.

The loss of CO_2 from the body reduces blood levels of carbonic acid and thereby adjusts the pH upward, toward normal levels.

This process also works in the opposite direction.

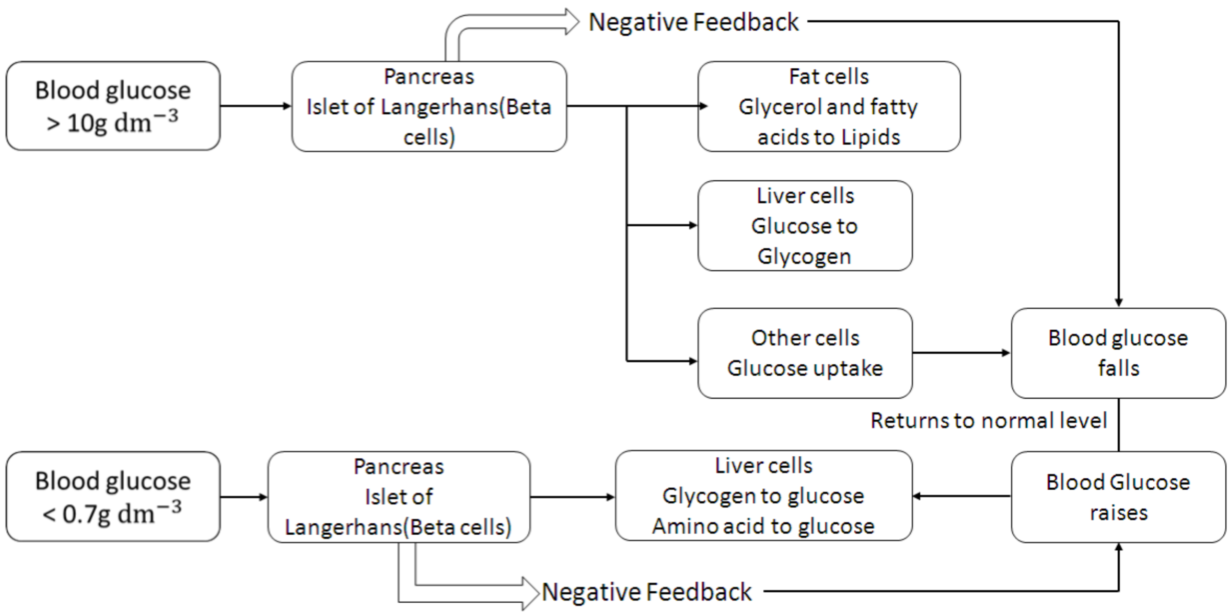
Excessive deep and rapid breathing (as in hyperventilation) rids the blood of CO_2 and reduces the level of carbonic acid, making the blood too alkaline.

This brief alkalosis can be remedied by rebreathing air that has been exhaled into a paper bag.

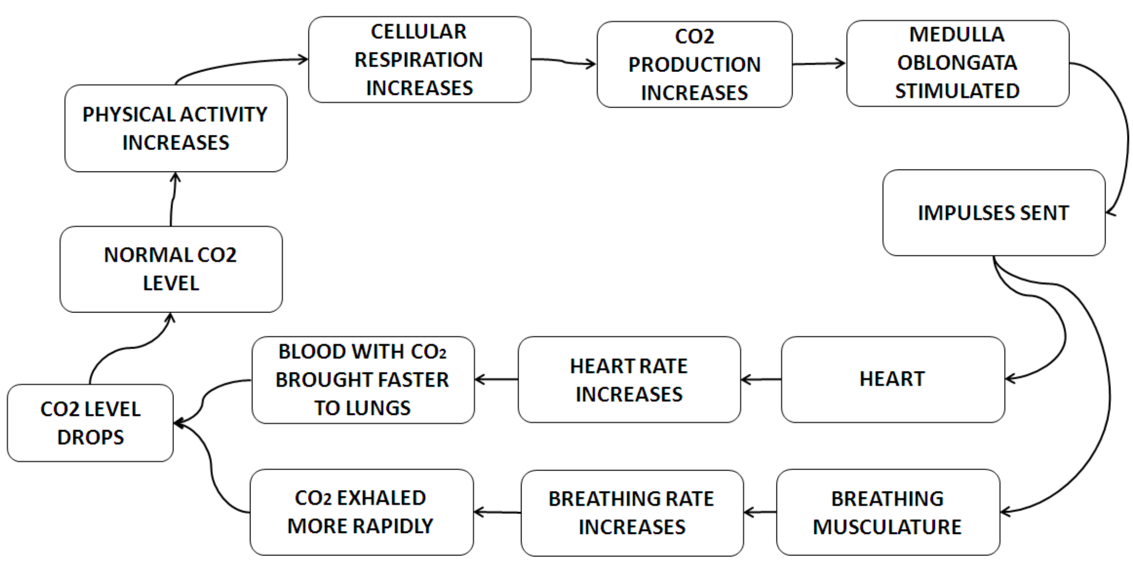
Rebreathing exhaled air will rapidly bring blood pH down toward normal.

The normal level of Ph is 7.35-7.45.

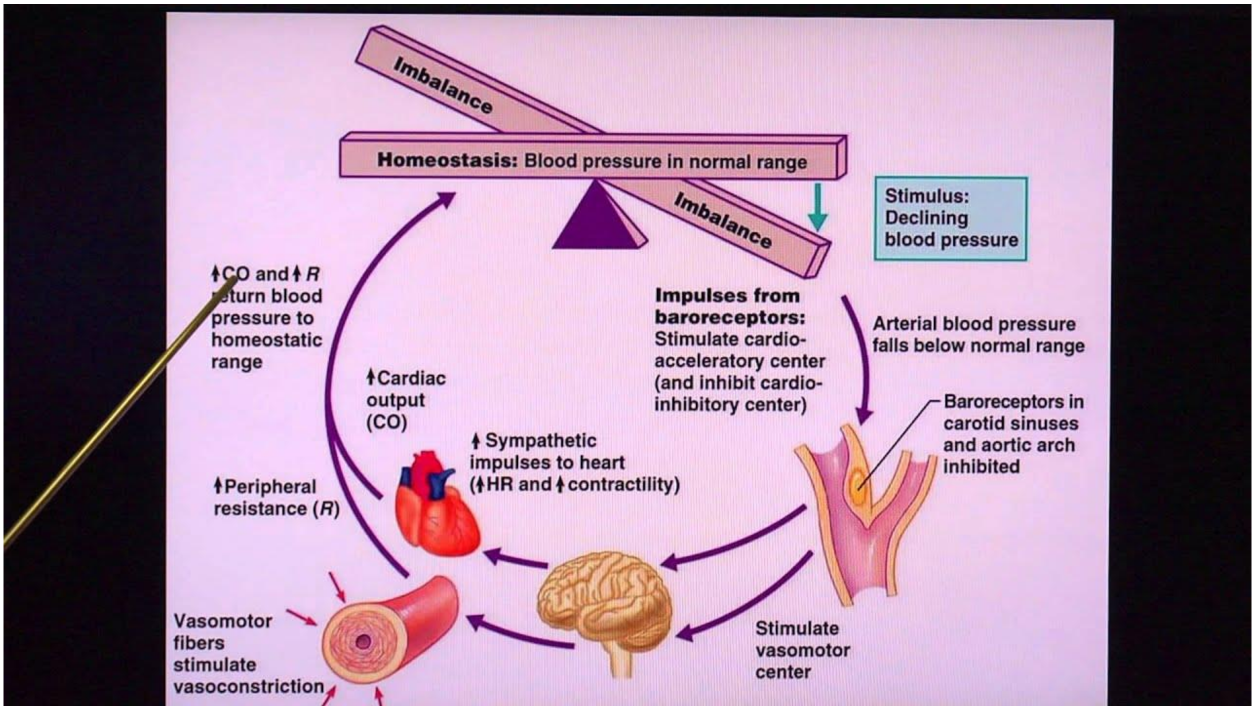
BLOOD GLUCOSE REGULATION
(Refer class notes)



CO_2 REGULATION:



BLOOD PRESSURE REGULATION:
There are two basic mechanisms for regulating blood pressure:
(1) short-term mechanisms, which regulate blood vessel diameter, heart rate and contractility
(2) long-term mechanisms, which regulate blood volume



Blood pressure is a measure of how well our cardiovascular system is functioning. We all require a blood pressure high enough to give our organs the blood and nutrients they need, but not so high our blood vessels become damaged.

As such, our bodies must maintain control over our blood pressure to keep it at a normal level. In this article, we will consider the short term and long term control of blood pressure, as well as some of the problems when control of blood pressure is lost.

BLOOD PRESSURE
The body's blood pressure is a measure of the pressures within the cardiovascular system during the pumping cycle of the heart. It is influenced by a vast number of variables, and can alter in either direction for various reasons. Everyone's blood pressure is slightly different and can change throughout the day depending on activity.

There is a range of normal blood pressures that we consider as acceptable. When blood pressure is outside of this normal range of values, people can start to have problems in both the long and short term. Our body tries to maintain a stable blood pressure in the process of homeostasis.

Blood pressure is measured using an automated blood pressure monitor, or manually using a stethoscope and sphygmomanometer. It is given as two values (eg 120/80 mmHg), measured in "millimetres of mercury (mmHg)":

Systolic pressure – the first number (120 mmHg in the example) is the pressure of the blood during the heart contraction.
Diastolic pressure – the second number (80 mmHg in the example) is the pressure of the blood after one contraction but before the next contraction.

Short-Term Regulation of Blood Pressure
Short-term regulation of blood pressure is controlled by the autonomic nervous system.

Changes in blood pressure are detected by baroreceptors. These are located in the arch of the aorta and the carotid sinus.

Increased arterial pressure stretches the wall of the blood vessel, triggering the baroreceptors. These baroreceptors then feedback to the autonomic nervous system. The ANS then acts to reduce the heart rate and cardiac contractility via the efferent parasympathetic fibres (vagus nerve) thus reducing blood pressure.
Decreased arterial pressure is detected by baroreceptors, which then trigger a sympathetic response. This stimulates an increase in heart rate and cardiac contractility leading to an increased blood pressure.
Baroreceptors cannot regulate blood pressure long-term. This is because the mechanism of triggering baroreceptors resets itself once a more adequate blood pressure is restored.

Long-Term Regulation of Blood Pressure
There are several physiological mechanisms that regulate blood pressure in the long-term, the first of which is the renin-angiotensin-aldosterone system (RAAS).

Renin-Angiotensin-Aldosterone System (RAAS)
Renin is a peptide hormone released by the granular cells of the juxtaglomerular apparatus in the kidney. It is released in response to:

Sympathetic stimulation
Reduced sodium-chloride delivery to the distal convoluted tubule
Decreased blood flow to the kidney
Renin facilitates the conversion of angiotensinogen to angiotensin I which is then converted to angiotensin II using angiotensin-converting enzyme (ACE).

Angiotensin II is a potent vasoconstrictor. It acts directly on the kidney to increase sodium reabsorption in the proximal convoluted tubule. Sodium is reabsorbed via the sodium-hydrogen exchanger. Angiotensin II also promotes release of aldosterone.

ACE also breaks down a substance called bradykinin which is a potent vasodilator. Therefore, the breakdown of bradykinin potentiates the overall constricting effect.

Aldosterone promotes salt and water retention by acting at the distal convoluted tubule to increase expression of epithelial sodium channels. Furthermore, aldosterone increases the activity of the basolateral sodium-potassium ATP-ase, thus increasing the electrochemical gradient for movement of sodium ions.

More sodium collects in the kidney tissue and water then follows by osmosis. This results in decreased water excretion and therefore increased blood volume and thus blood pressure.

Anti-Diuretic Hormone (ADH)

The second mechanism by which blood pressure is regulated is release of Anti Diuretic Hormone (ADH) from the OVLT of the hypothalamus in response to thirst or an increased plasma osmolarity.

ADH acts to increase the permeability of the collecting duct to water by inserting aquaporin channels (AQP2) into the apical membrane.

It also stimulates sodium reabsorption from the thick ascending limb of the loop of Henle. This increases water reabsorption thus increasing plasma volume and decreasing osmolarity.

Further Control of Blood Pressure

Other factors that can affect long-term regulation of blood pressure are natriuretic peptides. These include:

Atrial natriuretic peptide (ANP) is synthesised and stored in cardiac myocytes. It is released when the atria are stretched, indicating of high blood pressure.
ANP acts to promote sodium excretion. It dilates the afferent arteriole of the glomerulus, increasing blood flow (GFR). Moreover, ANP inhibits sodium reabsorption along the nephron. Conversely, ANP secretion is low when blood pressure is low.
Prostaglandins act as local vasodilators to increase GFR and reduce sodium reabsorption. They also act to prevent excessive vasoconstriction triggered by the sympathetic nervous and renin-angiotensin-aldosterone systems.

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UNIT 3
MODELING OF HUMAN THERMAL REGULATORY SYSTEM

S. Sree Sanjanaa Bose

AP/BME

- Digestion is the Physico-chemical process by which complex food materials are broken down to simple absorbable units.
- Basic process of digestion is hydrolysis catalyzed by the hydrolases group of enzymes (digestive enzymes).
- Digestion occurs in the lumen of GIT aided by the digestive enzymes of digestive juices.
- Absorption is the chemical process by which the end products of digestion pass through the intestinal epithelium to enter the lymph or blood stream.

Digestion of Carbohydrate

- Important dietary carbohydrates are starch,lactose & sucrose.
- Carbohydrate digestion starts from mouth.

➢ In the mouth: Salivary α-amylase hydrolyzes starch into maltose, maltotriose & α-limit dextrin.

➢ In stomach: The function of ptyalin is lost. Here some sucrose hydrolyzed by HCL.

- $\text{Sucrose} \xrightarrow{\text{HCL}} \text{Glucose + Fructose}$

Digestion of Proteins

- In the mouth: No digestion of proteins occurs.
- In the stomach: In stomach gastric HCL causes protein denaturation & pepsin digest protein to smaller polypeptides & amino acid.
- In small intestine: Most protein digestion occurs in lumen of duodenum & jejunum.

Smaller Polypeptides → Oligopeptides + Amino acids
(trypsin, chymotrypsin, carboxypeptidase)

Oligopeptides → Dipeptides, tripeptides, amino acid
(Aminopeptidase, dipeptidase, tripeptidase)

- Absorption of Amino acid
- 	 Absorption of amino acids take place in
- duodenum & jejunum.
- 	 End products of protein digestion are a mixture of
- free amino acids, dipeptides & tripeptides, all of
- which are actively absorbed from lumen to cells
- (enterocyte).
- 	 Free amino acids are absorbed from lumen to cell
- by sodium dependent secondary active transport
- process (sodium cotransport of amino acid).

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- In stomach: The function of ptyalin is lost. Here
- some sucrose hydrolyzed by HCL.
- HCL
- Sucrose-------------------- Glucose + Fructose

Digestion of Carbohydrate

- In the duodenum:

Pancreatic α-amylase

Starch Maltose, maltotriose, α-limit dextrin

- In the small intestine:

Maltose Glucose + Glucose (Maltase)

Maltotriose Glucose (Maltase)

Lactose Glucose + Galactose (Lactase)

Sucrose Glucose + Fructose (Sucrase)

α-limit dextrin Glucose (α-limit dextrinase)

Absorption of Carbohydrate

End products of CHO digestion	Transport from lumen to enterocyte		Transport from enterocyte to ECF & blood	
	Process	Carrier protein	Process	Carrier protein
Glucose Galactose	Secondary active transport	SGLT-1	Facilitated diffusion	GLUT-2
Fructose	Facilitated diffusion	GLUT-5	Facilitated diffusion	GLUT-2

Lactose Intolerance

- Lactose intolerance is an inability to digest &
- absorb lactose that results in gastrointestinal
- symptoms when milk or milk products are
- consumed.
- Causes:
- 1. Reduced or absent activity of the enzyme lactase.
- 2. A congenital absence of lactase enzyme from
- birth due to mutation of lactase producing gene.
- 3. Some diseases e.g. celiac sprue.

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- Smaller Polypeptides Oligopeptides + Amino acids
- (trypsin, chymotrypsin, carboxypeptidase)
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- (Aminopeptidase, dipeptidase, tripeptidase)

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❖ Free amino acids are absorbed from lumen to cell

- by sodium dependent secondary active transport
- process (sodium cotransport of amino acid)

Digestion of lipid

- ➢ Dietary fat: TAG, Phospholipid, Cholesteryl ester,
- Free fatty acid, Free cholesterol (very small amount).
- ➢ In stomach: Lipid digestion begins in stomach by acid
- stable lingual lipase. Lingual lipase cannot start lipid
- digestion in mouth because optimum pH for action of
- lingual lipase is 4-4.5 whereas pH of saliva is about 7.0.
- Here only milk fat is partially hydrolyzed by lingual
- lipase associated with gastric lipase which is true only
- in neonates & infants. 30% fat digestion occurs in
- stomach by the action of lipases. This lipases are
- specially important in case of cystic fibrosis with near
- or complete absence of pancreatic lipase.

Digestion of lipid

- In duodenum:
- In duodenum fat undergoes emulsification process by
- which large fat particles are broken down into smaller
- fine particles that increase the surface area of fat/oil,
- so that digestive enzymes can work effectively. This
- process done by bile salts & lecithin that reduce the
- surface tension of fat particles by detergent action.
- After emulsification, pancreatic lipase with the help of
- colipase digests TAG, removing FA from 1st & 3rd
- carbon of glycerol & produces 2-MAG.

- TAG-----------2-MAG + Fatty acid (Lipase + Colipase)
- 2-MAG----Fatty acid + Glycerol (Lipase + Colipase

Digestion of lipid

- Dietary Cholesteryl ester is digested by pancreatic
- Cholesteryl esterase to fatty acid & free
- cholesterol. Bile salts enhance the activity of
- Cholesteryl esterase.
- Cholesteryl ester--------Cholesterol + Fatty acid
- (Cholesteryl esterase).
- � Dietary Phospholipid is digested by pancreatic
- phospholipase A2 removing fatty acid from 2nd
- carbon of glycerol moiety & produces
- lysophospholipid.
- PL-----------Lysophospholipid + Fatty acid
- (Phospholipase-A2)

- Therefore final end product of lipid digestion is
- fatty acid, glycerol, 2-MAG, free cholesterol &
- lysophospholipid.
- ◑ The process of emulsification occurs by three
- complimentary mechanisms-
- ⇒ Detergent action of bile salts.
- ⇒ Surfactant action of degraded lipids.
- ⇒ Mechanical mixing due to peristalsis.

Abnormalities of Lipid digestion & Absorption

- Steatorrhea: It is a condition characterized by the
- loss of lipids in the feces. Steatorrhea may be due
- to

✓ A defect in the secretion of bile or pancreatic

- juice into the intestine.

✓ Impairment in the lipid absorption by the

- intestinal cells.

✓ Steatorrhea is commonly seen in disorders

- associated with pancreas, biliary obstruction,
- severe liver dysfunction etc.

Abnormalities of Protein digestion & Amino acid absorption

- Hartnup's disease (neutral amino aciduria):

❑ Hartnup is the name of the family in whom this

- disease was first discovered.

❑ It is characterized by the inability of intestinal and

- renal epithelial cells to absorb neutral amino acids
- (cysteine, methionine, tryptophan, glycine etc.).

❑ Tryptophan absorption is most severely affected

- with a result that typical symptoms of Pellagra are
- observed in the patients of Hartnup's disease.

Abnormalities related to HCL secretion

- Achlorhydria: An absence of free HCL in the
- stomach, is called achlorhydria. It occurs due to
- gastric carcinoma, pernicious anemia,
- adrenal insufficiency, chronic gastritis.

❖ Hyperchlorhydria: An excess of free HCL in the
- stomach. It founds in Zollinger-Ellison syndrome,
- Duodenal ulcer.

❖ Hypochlorhydria: Decrease free HCL concentration
- in stomach. It founds in pernicious anemia, gastric
- carcinoma.

Temperature and Heat

- Temperature:
- measure of the average kinetic energy associated with the

disordered motion of atoms and molecules.

- Heat:
- state of energy an object has in relation to the kinetic energy

of its molecules or atoms.

- Second law of thermodynamics:
- Energy will disperse from a concentrated form to a dilute
- form if it is not hindered from doing so.
- Energy will move from high to low states.
- Thus heat moves from high temperature to low temperature.

- Inter threshold range:
- Range of core BODY temperature over which no autonomic
- thermoregulatory response occur.
- Also can be considered “range of core temperature that the
- body is most economical with energy” since no energy is
- expended to increase or decrease temperature.
- Narrow range: 36.5 – 37.5 C (In some references) but 36.8 to
- 37.2 C (according to Peter Kam).

- Thermoneutral zone:
- Range of ENVIRONMENTAL temperature in which the
- metabolic rate is minimal.
- Also can be considered “range of environmental
- temperature that the body is most economical with energy”
- since no energy is expended to increase or decrease
- temperature.
- Range wider and more variable.
- Environmental acclimatization.
- World Cup in Brazil

Mechanism of Heat Loss

- Thermal Radiation (40%
- Convection (30%)
- Evaporation (15%)
- Respiration (10%)
- Conduction (5%)

❑Thermal Radiation (40%)

- Largest mechanism of heat loss.
- A form of electromagnetic radiation
- Occurs without the presence of a medium.
- Reflective blankets for hypothermic patients or patients with
- burns.

Mechanism of Heat Loss

- Convection (30%)
- Refers to the movement of molecules away from a warm
- object as a consequence of their reduced density as they gain
- heat and expand.
- This creates convection currents, which transfer heat away
- from the object.
- A medium is needed for convection.
- Covering the patient with a blanket to reduce convection.
- Forced air warmer to introduce warm convection currents.

Mechanism of Heat Loss

- Evaporation (15%)
- Latent heat of vaporization.
- When a liquid converts to a gas, it needs to gain energy.
- This energy in the form of heat is taken from the patient.
- Wrapping neonates with non-permeable films.

Mechanism of Heat Loss

- Respiration (10%)
- A form of evaporative heat loss.
- Can’t stop the patient breathing, can you?
- So use of HME in circuits.

Mechanism of Heat Loss

- Conduction (5%)
- Occurs between two objects in direct contact where a
- temperature gradient exists between them.
- Use of warming mattresses, warmed blankets.

Thermoregulation

- Essentially a feedback loop involving an:
- Afferent System (sensor)
- Central Processor
- Efferent System (effector)

- ➢ Essentially a feedback loop involving an:
- Afferent System (sensor)
- Peripheral
- Skin cold receptors: CMR-1, via A delta and C fibres, fire maximally at 25-
- 30 deg C
- Skin warm receptors: VR1 and VRL-1, via C fibres, fire maximally at 45-
- 50 deg C
- Central
- Receptors in spinal cord, afferents travel lateral spinothalamic tracts to
- medulla to hypothalamus.

Hyperthermia Response

❖ Peripheral
- Skin
- Vasodilation/increase cutaneous blood flow via arteriovenous

❖ shunts.
- Increase radiation, convection, conduction.

❖ Sweat glands
- Increase sweating
- Increase evaporation
- Shivering and Non shivering thermogenesis inhibited

Hyperthermia Response

- Central
  - Cerebrum: behavioral changes.
  - Lethargy: decrease metabolic rate.
  - Increase fluid intake
  - Fanning
  - Removing excessive clothing
  - Looking for shade

Hypothermic response

- Peripheral
- Skin
- Vasoconstriction/decrease cutaneous blood flow via arteriovenous shunts.
- Decrease radiation, convection, conduction.
- Sweat glands
- Decreases sweating
- Minimize evaporation

Hypothermic response

- Peripheral
- Shivering:
- Uncoordinated large muscle group contraction.
- Metabolic heat generated from mechanical work.

- Non shivering thermogenesis:
- Oxidative phosphorylation in brown fat and muscle.
- Actived by beta 3 sympathetic activity.
- Metabolic heat production WITHOUT mechanical work.

Hypothermic response

- Central
- Cerebrum: behavioral changes.
- Wearing extra clothes.
- Increasing physical activity.
- Seeking heat.
- Consuming hot drinks.

3 Phases of Heat Loss

Phase 1:

- Rapid reduction in core temperature of 1.0–1.5°C within the
- first 30–45 min.
- Attributable to vasodilatation and other effects of general
- anaesthesia.

Phase 2:

- More gradual, linear reduction in core temperature of a
- further 1°C over the next 2–3 h of anaesthesia.
- Attributable to heat loss by radiation, convection and
- evaporation exceeding heat gain which is determined by the
- metabolic
- Rate

Phase 3:

- 'Plateau' phase where heat loss is matched by metabolic
- heat production.
- Occurs when anaesthetised patients become sufficiently
- hypothermic to reach the altered threshold for
- vasoconstriction which restricts the core-to- peripheral heat
- gradient.

Effects of Hypothermia

- Neurological System
- Linear depression in cerebral metabolism, amnesia, apathy,
- impaired judgement and maladaptive behaviour. Progressive
- deterioration until coma at 30°C.
- Progressive hyporeflexia. Shivering is replaced by muscular
- rigidity at about 33°C. Rigor mortis-like appearance at
- 24°C+/- involuntary flapping tremor
- Reduced CMRO2 with reduced CBF.
- Flat EEG at ~20°C

Preventing Hypothermia

- ➢ Adjusting ambient temperature
- Airway heating/humidification
- Warmed IV fluids
- Passive insulation
- Blanket
- Wrap
- Active warming
- Forced air mattress – works
- Circulating water mattress – minimally effective.
- Overhead infra red warming devices.

Brain: The body's thermostat

Sensory receptor (input):

- Thermoreceptors on skin sense temperature
- Integration: hypothalamus
- Contains neurons that respond to changes in
- body temperature above and below the
- normal range
- Effector (output):
- Behavioural changes
- Physiological changes (heat exchange,
- evaporative cooling, heat production,
- metabolic rate)

Cold Response:Physiological Changes

Rate of heat exchange decreases:

- Vasoconstriction of blood vessels near skin
- less blood to skin = less heat loss
- Blood redirected to torso (organs)
- Rate of heat production increases:
- muscles contract
- shivering generates heat
- Rate of metabolic heat production increases:
- brown adipose (fat) tissue metabolism

UNIT-IV
BIOLOGICAL CONTROL I

S.Sree Sanjanaa Bose
AP/BME

Cardiac Cycle

Definition:

- “ The cardiac events that occur from the beginning of one heart beat to the beginning of the next “.

Time:

- Average duration of each cycle is 0.8 second (60 seconds/75 beats.min-)

Phases of Cardiac Cycle

- I- Atrial systole:
- II- Ventricular systole (0.3 sec), which includes:
  - a- Isometric (or isovolumetric) contraction phase.
  - b- Maximum ejection phase.
  - c- Reduced ejection phase.
- III- Ventricular diastole (0.5 sec), which includes:
  - a- Isometric (or isovolumetric) relaxation phase.
  - b- Rapid filling phase.
  - c- Reduced filling phase.

Cardiac Rate

- In a normal adult male, the average heart beats at rest is approximately 70 beats/ minute.
- Methods of counting the HR:
  a) Counting the radial pulse or apex beats/min.
  b) Counting the cardiac cycles or heart sounds by stethoscope.
  c) Recording the ECG.

Regulation of the heart rate

I- Nervous

– **Impulses from higher centers: cerebral cortex, hypothalamus, respiratory center**

– **Afferent impulses from right & left side of circulation**

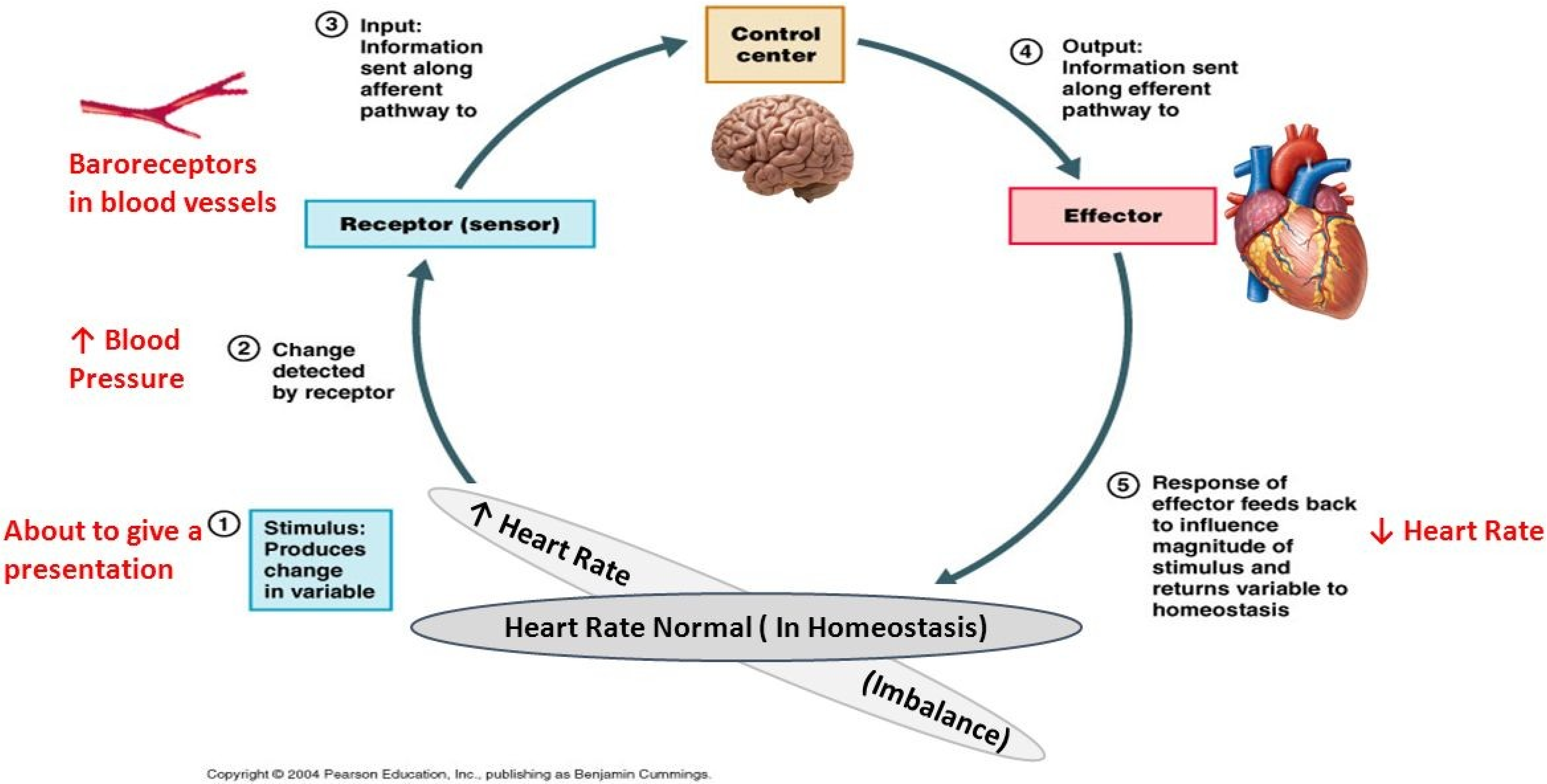
II- Chemical:

– **Blood gases, hormones, others**

III. Physical:

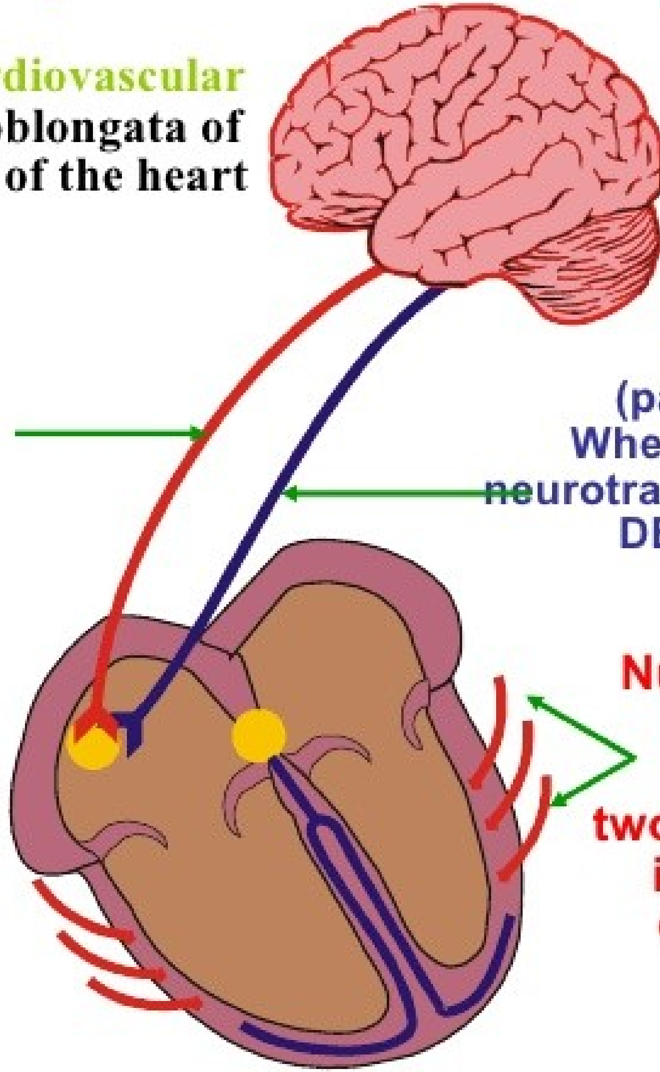
– **Blood temperature**

Negative Feedback System-Heart Rate



1. Nervous System controlling Heart Rate

Two nerves link the cardiovascular centre in the medulla oblongata of brain with the SA node of the heart



1. Accelerator nerve (sympathetic NS). When stimulated, releases neurotransmitter at the SA node to INCREASE heart rate

2. Vagus nerve (parasympathetic NS). When stimulated, releases neurotransmitter at the SA node to DECREASE heart rate

Numerous sympathetic nerves also link to the walls of the two ventricles where they increase the force of contraction of these chambers

Blood Pressure

- Definition : Arterial blood pressure can be defined as the lateral pressure exerted by the moving column of blood on the walls of the arteries.
- Normal Adult range Can fluctuate within a wide range and still be normal

Systolic/diastolic: 100/60 - 140/80

Significance

1. To ensure the blood flow to various organs.
2. Plays an important role in exchange of nutrients and gases across the capillaries.
3. Required to form urine.
4. Required for the formation of the lymph.

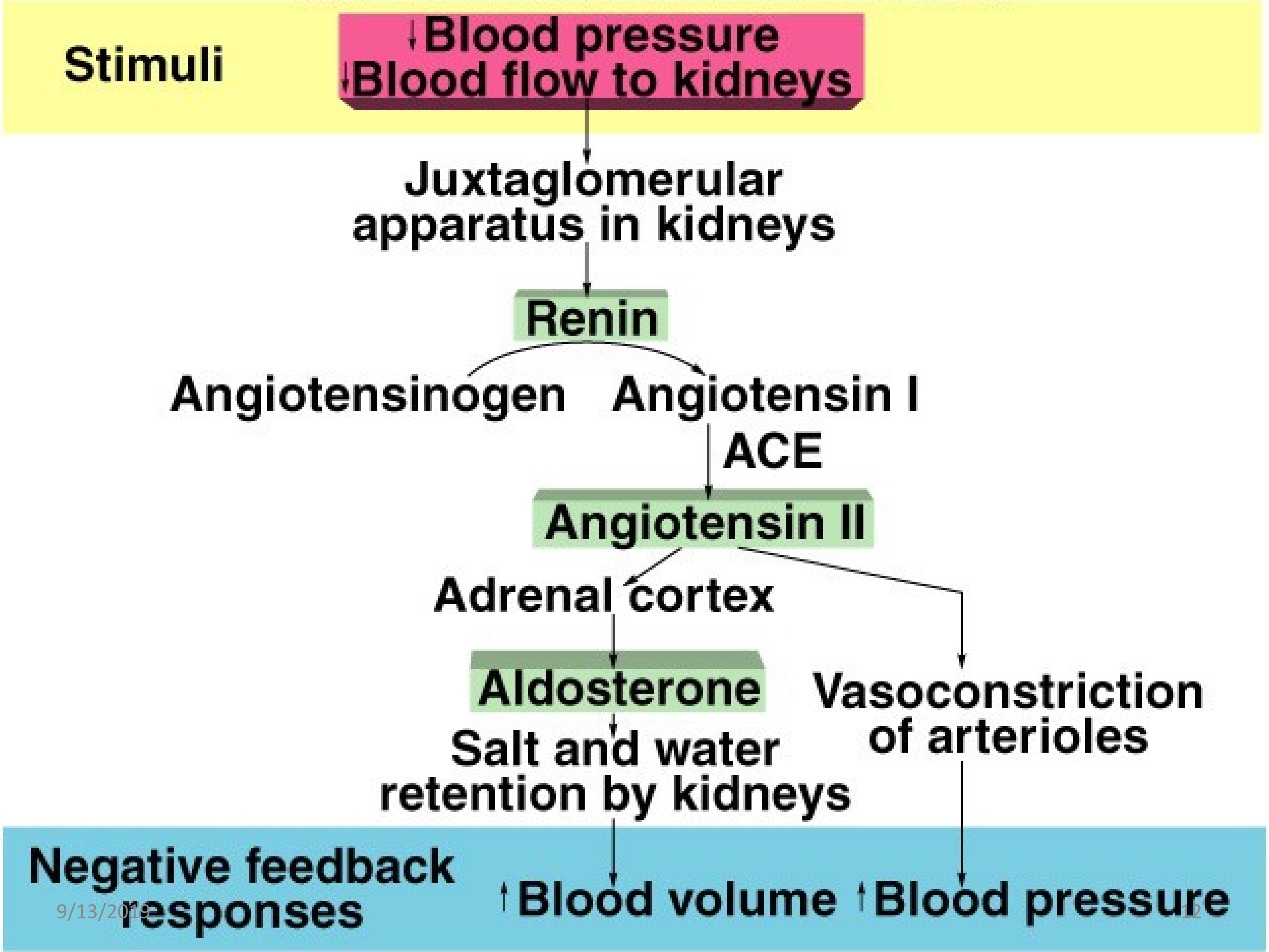
REGULATION OF ARTERIAL BLOOD PRESSURE

- Immediate mechanism
- Short term mechanism
- Long term mechanism

Immediate Regulatory Mechanisms:

Neural mechanisms

1. Baroreceptor reflexes
2. Chemo receptor reflexes
3. Cerebral ischaemic response


Stimuli
↓Blood pressure
↓Blood flow to kidneys
Juxtaglomerular apparatus in kidneys
Renin
Angiotensinogen
Angiotensin I
ACE
Angiotensin II
Adrenal cortex
Aldosterone
Salt and water retention by kidneys
Vasoconstriction of arterioles
Negative feedback responses
↑Blood volume
↑Blood pressure

Respiratory Rate

- The respiration rate is the number of breaths a person takes per minute.
- The rate is usually measured when a person is at rest and simply involves counting the number of breaths for one minute by counting how many times the chest rises.
- Respiration rates may increase with fever, illness, and other medical conditions.
- When checking respiration, it is important to also note whether a person has any difficulty breathing.
- Normal respiration rates for an adult person at rest range from 12 to 16 breaths per minute.

Regulation

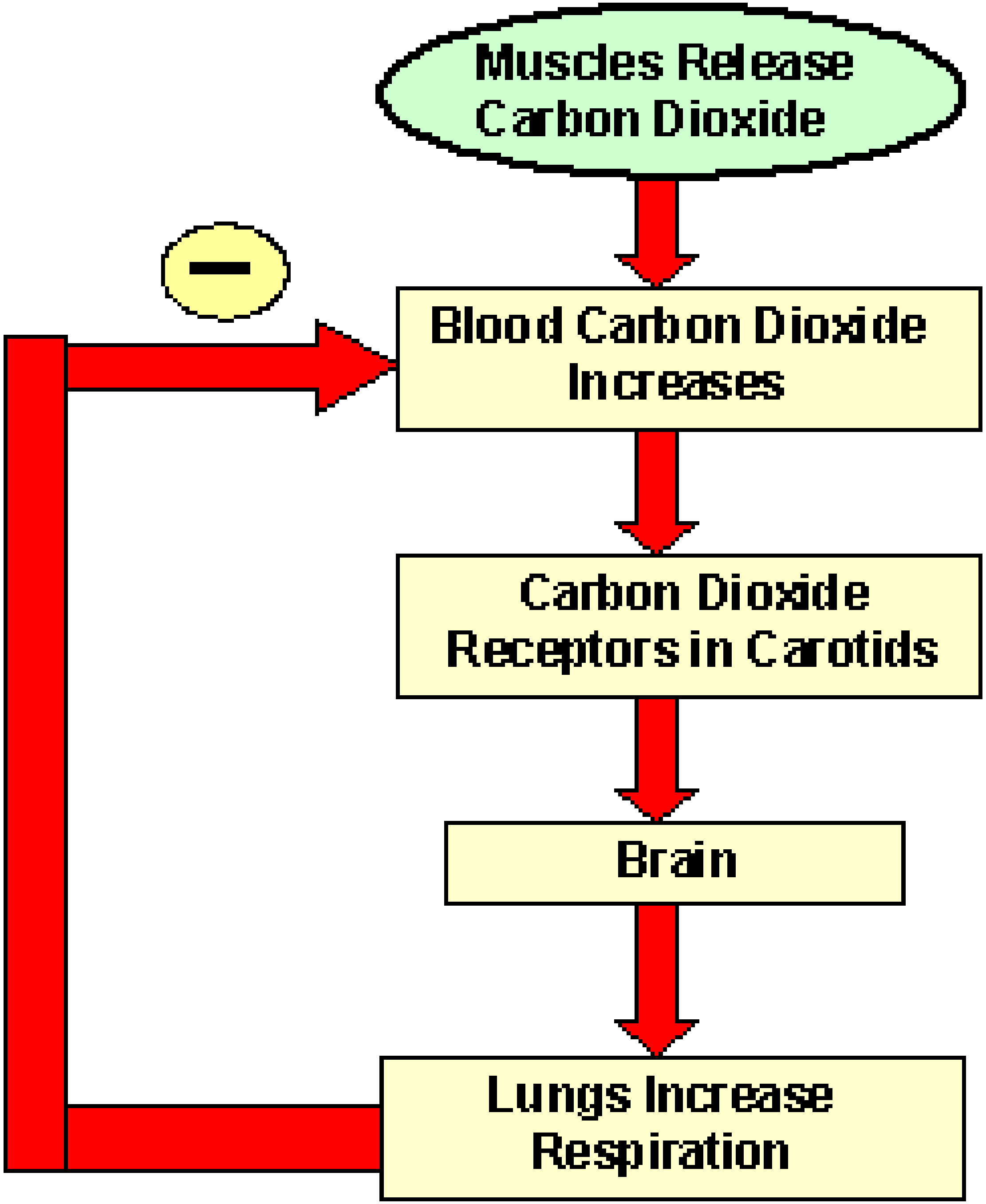
- The medulla oblongata is the primary respiratory control center. Its main function is to send signals to the muscles that control **respiration** to cause breathing to occur. There are two regions in the medulla that control **respiration**: The ventral respiratory group stimulates expiratory movements.

Nerves Used in Respiration

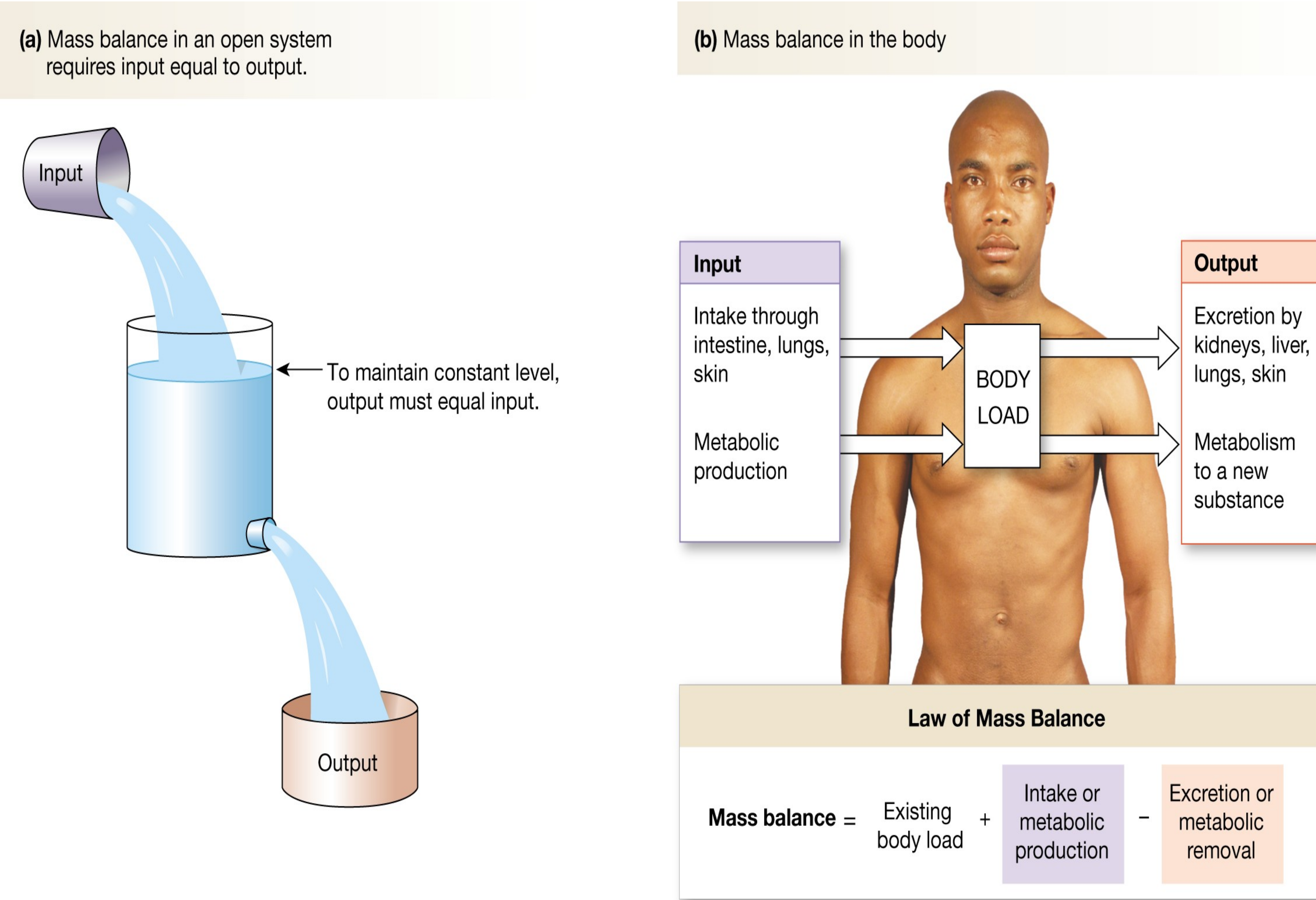
- There are three types of important respiratory nerves:
- The phrenic nerves: The nerves that stimulate the activity of the diaphragm. They are composed of two nerves, the right and left phrenic nerve, which pass through the right and left side of the heart respectively.
- The vagus nerve*:* Innervates the diaphragm as well as movements in the larynx and pharynx. It also provides parasympathetic stimulation for the heart and the digestive system.
- The posterior thoracic nerves: These nerves stimulate the intercostal muscles located around the pleura.

Mass Balancing of Lungs

- The Law of Mass Balance:
- Total amount of substance x in the body = intake + production - excretion – metabolism



Muscles Release Carbon Dioxide
Blood Carbon Dioxide Increases
Carbon Dioxide Receptors in Carotids
Brain
Lungs Increase Respiration


(a) Mass balance in an open system requires input equal to output.
Input
To maintain constant level, output must equal input.
Output
(b) Mass balance in the body
Input
Intake through intestine, lungs, skin
Metabolic production
BODY LOAD
Output
Excretion by kidneys, liver, lungs, skin
Metabolism to a new substance
Law of Mass Balance
Mass balance = Existing body load + Intake or metabolic production − Excretion or metabolic removal

Oxygen Transport in Blood and Tissues

- Although oxygen dissolves in blood, only a small amount of oxygen is transported this way.
- Only 1.5 percent of oxygen in the blood is dissolved directly into the blood itself.
- Most oxygen—98.5 percent—is bound to a protein called hemoglobin and carried to the tissues.

- Hemoglobin, or Hb, is a protein molecule found in red blood cells (erythrocytes) made of four subunits: two alpha subunits and two beta
- Subunits.
- Each subunit surrounds a central heme group that contains iron and binds one oxygen molecule, allowing each hemoglobin molecule to bind four oxygen molecules.
- Molecules with more oxygen bound to the heme groups are brighter red

- It is easier to bind a second and third oxygen molecule to Hb than the first molecule.
- This is because the hemoglobin molecule changes its shape, or conformation, as oxygen binds.
- The fourth oxygen is then more difficult to bind.

- The oxygen-carrying capacity of hemoglobin determines how much oxygen is carried in the blood.
- In addition to , other environmental factors and diseases can affect oxygen carrying capacity and delivery.
- Carbon dioxide levels, blood pH, and body temperature affect oxygen carrying capacity

Carbon Dioxide Transport in Blood and Tissues

- Carbon dioxide can be transported through the blood via three methods.
- It is dissolved directly in the blood, bound to plasma proteins or hemoglobin, or converted into bicarbonate.

- The majority of carbon dioxide is transported as part of the bicarbonate system. Carbon dioxide diffuses into red blood cells.
- Inside, carbonic anhydrase converts carbon dioxide into carbonic acid (H2CO3), which is subsequently hydrolyzed into bicarbonate and H+.

- The H+ ion binds to hemoglobin in red blood cells, and bicarbonate is transported out of the red blood cells in exchange for a chloride ion.
- This is called the chloride shift.
- Bicarbonate leaves the red blood cells and enters the blood plasma.
- In the lungs, bicarbonate is transported back into the red blood cells in exchange for chloride.
- The H+ dissociates from hemoglobin and combines with bicarbonate to form carbonic acid with the help of carbonic anhydrase, which further catalyzes the reaction to convert carbonic acid back into carbon dioxide and water.
- The carbon dioxide is then expelled from the lungs

Gas Exchange Between the Blood and Alveoli

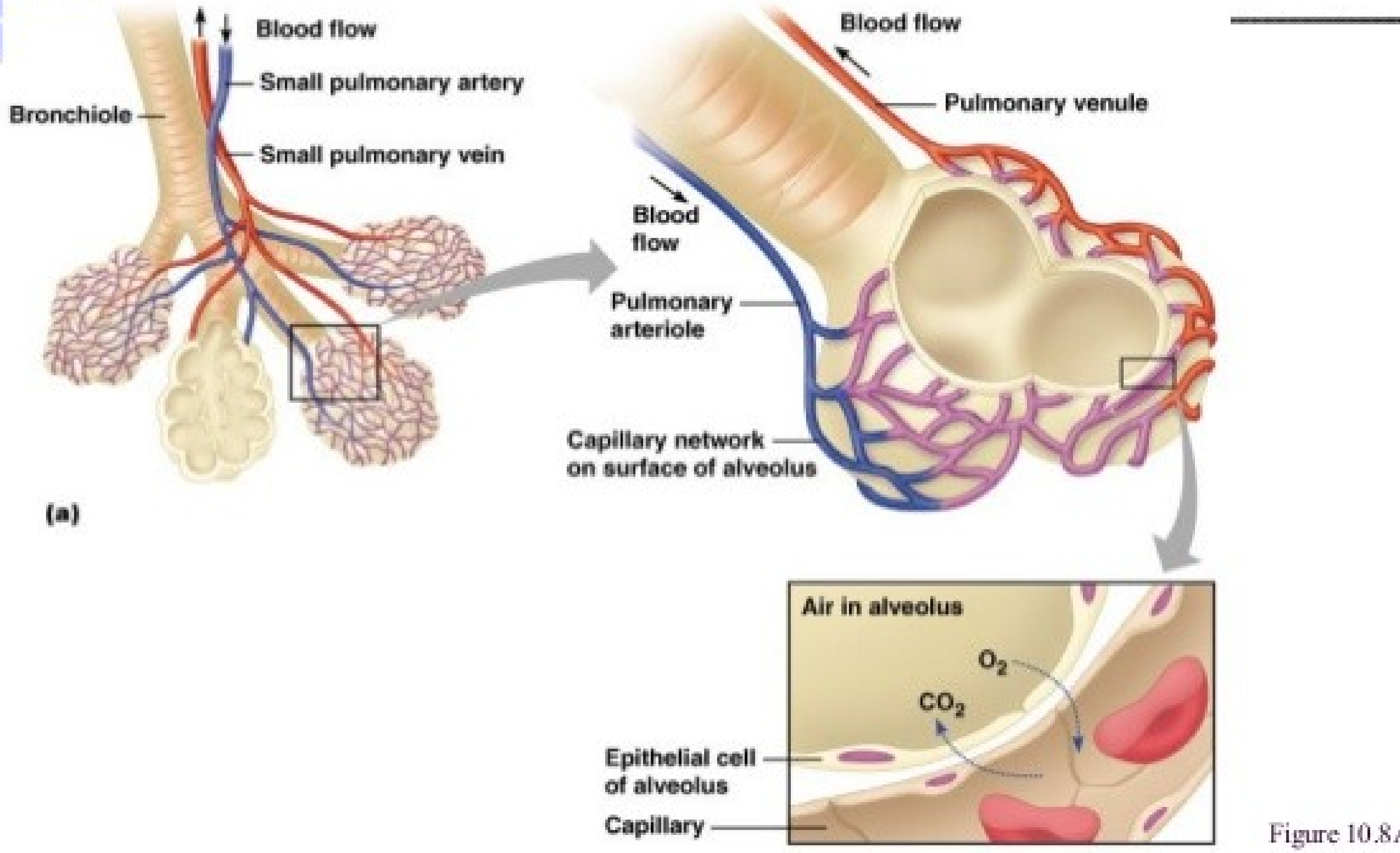


Figure 10.8A

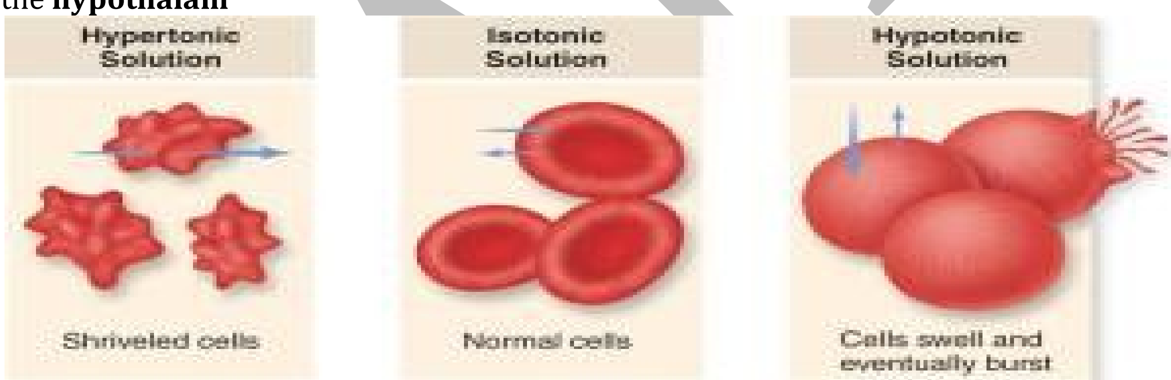
FORMATION OF URINE:

The main function of the kidneys is **EXCRETION**. They remove **urea** from the blood in a two stage process described in an earlier post, first by **filtering** the blood under high pressure in the glomerulus and then selectively **reabsorbing** the useful substances back into the blood as the filtrate passes along the nephron. But the kidney has an equally important role in **HOMEOSTASIS**. It actually is the main effector organ for regulating a whole load of variables about the composition of the blood (e.g. blood pH and salt balance) but in this post I want to explain to you how the water balance of the body is regulated and the kidney's role in this homeostatic system.

Why do you need to regulate the dilution (or water potential) of the blood?

If the blood becomes **too dilute**, then water will enter all the body cells by **osmosis** (from a dilute to a more concentrated solution). This net movement into cells would cause them to swell and eventually **burst**. Bad news all round. If the blood becomes **too concentrated**, then water will leave the body cells by **osmosis**. Cells will **shrivel** up as they lose water into the blood and this will kill them. Bad news all round….

Remember: a hypertonic solution has a low water potential and is very concentrated. A hypotonic solution has a very high water potential and is very dilute. The regulation of the water potential of the blood is a very important example of **homeostasis** in the human. It is often referred to as **OSMOREGULATION**. The water potential (dilution) of the blood is measured continuously by a group of neurones in a region of the brain called the **hypothalam**



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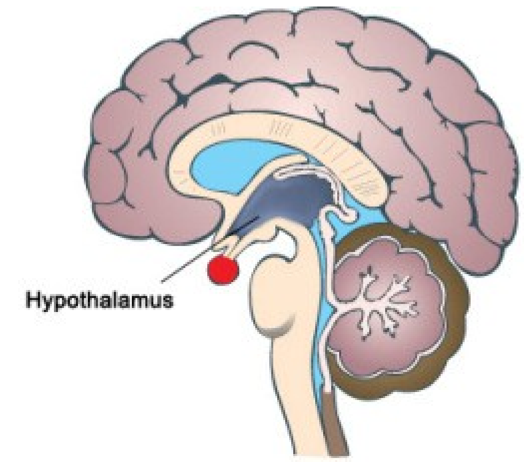
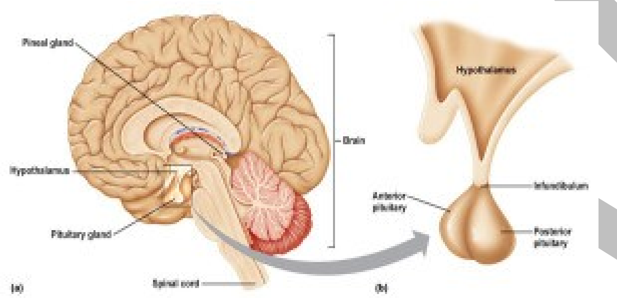
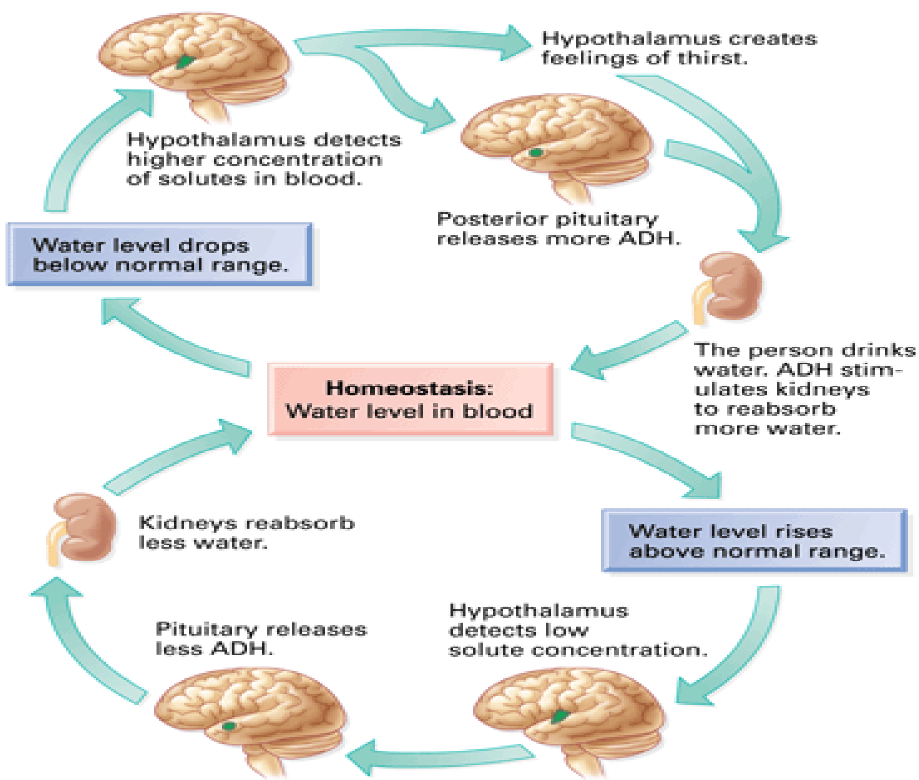


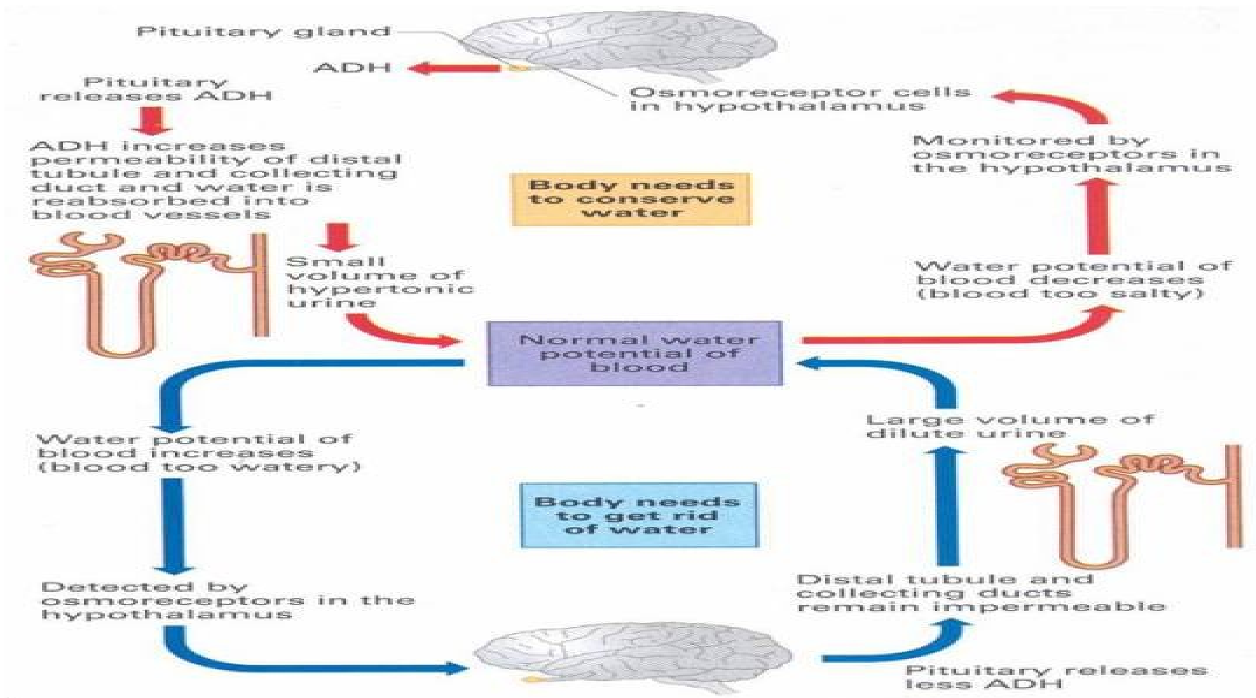
The hypothalamus is found right next to a very important hormone-secreting gland called the **pituitary gland**, marked as the red circular structure on the diagram above. When the hypothalamus detects that the blood's water potential is dropping (i.e. it is getting **too concentrated**) this causes the posterior lobe of the pituitary gland to start secreting a hormone **ADH** into the bloodstream.



Hormones such as ADH exert their effects elsewhere in the body. The main **target tissue** for **ADH** is the **collecting duct walls** in the kidney. ADH binds to receptors on these cells and makes the wall of the collecting duct **much more permeable to water**. This means as the urine passes down the collecting duct through the salty medulla of the kidney, lots of water can be reabsorbed into the blood by osmosis. This leaves a small volume of very concentrated urine and water loss is minimised.ADH is secreted whenever the body is **dehydrated**. It might be because the person is losing plenty of water in sweating in which case it is vital that the kidney produces as small a volume of urine as is possible.

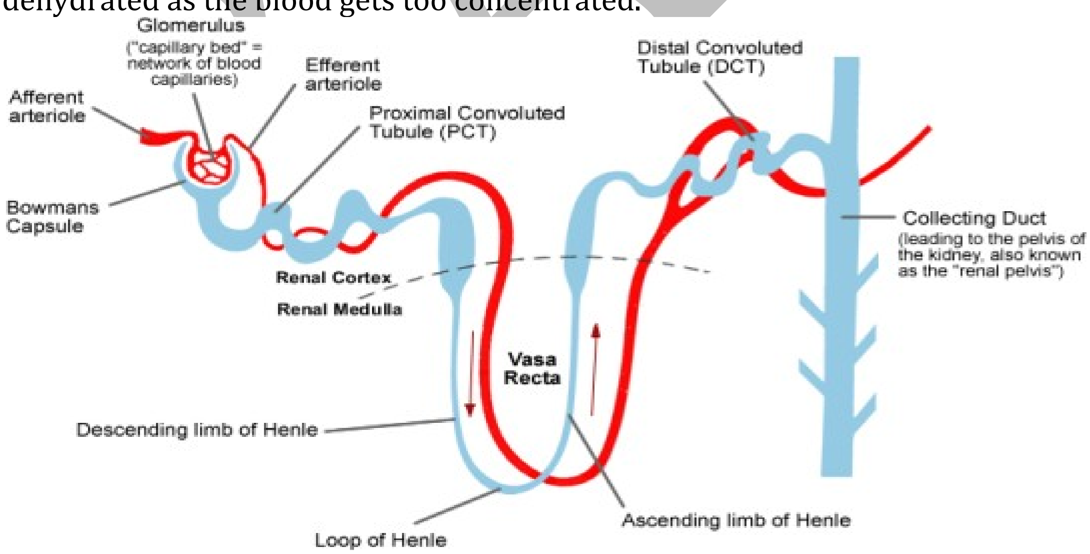


If you drink a litre of water, what effect will this have on the dilution of the blood: of course it makes the blood **more dilute**. This will be detected in the hypothalamus by **osmo receptors** and they will cause the pituitary gland to **stop** secreting ADH into the bloodstream. If there is no ADH in the blood, the walls of the collecting duct remain totally **impermeable to water**. As the dilute urine passes down the collecting duct, no water can be reabsorbed into the blood by osmosis and so a large volume of dilute urine will be produced.

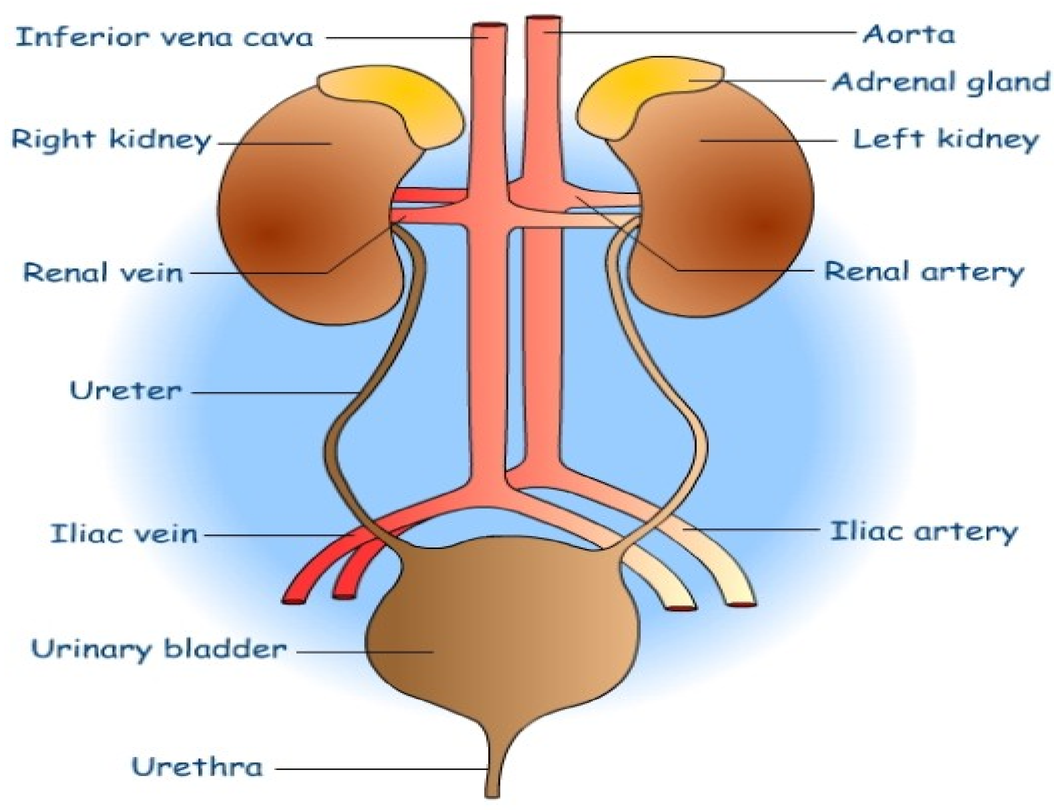


This is another beautiful example of **negative feedback** in homeostasis.

PMG tip: you can avoid getting confused in the exam about the effect of ADH if you can remember what it stands for. ADH is an acronym for **anti-diuretic hormone** (ADH). A **diuretic** is a drug that **promotes** urine production. They are banned drugs from WADA (World Anti-Doping Agency) since they can be taken as a masking drug to help flush out evidence of illegal drug taking. Shane Warne missed the 2003 cricket World Cup and served a ban for failing a drugs test due to diuretics in his sample.So an anti-diuretic hormone will **reduce** urine production. This means it will be secreted when the body is dehydrated as the blood gets too concentrated.



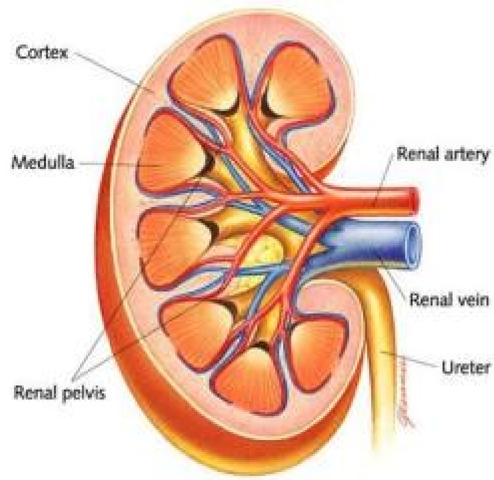
Finally remember that it is not the whole nephron that is affected by ADH, just the collecting ducts and part of the distal convoluted tubules. Most water in the glomerular filtrate is absorbed in the nephron but the collecting duct has a role in "fine-tuning" the volume and dilution of urine. This is a really important topic to master for an A* in your exam. Examiners seem to like asking questions on ADH and osmoregulation and often these questions are amongst the hardest marks to get in the exam, and so serve as a brilliant discriminator between A and A* candidates. Work hard to master this topic and with a little luck from the question-setters an A* grade is within your grasp. **Excretion** is defined as "the removal of waste molecules that have been produced in metabolism inside cells". So for example carbon dioxide is a waste product of respiration and is excreted in the lungs. The **liver** too produces a waste molecule **urea** from the breakdown of **amino acids**. Amino acids and proteins cannot be stored in the body: if you eat more than you use, the excess is broken down to urea. Urea would certainly become toxic if it was allowed to accumulate in the body (patients with no kidney function will die within 3-4 days without treatment) and the organ that is adapted to excrete urea from the blood is the **kidney**. Kidneys excrete urea by dissolving it in water, together with a few salts to form a liquid called urine.Urine is produced in the kidneys continuously day and night. It travels away from the kidney in a tube called the **ureter**. Each kidney has a ureter coming out of it, and the two ureters carry the urine to the **bladder**. The bladder is a muscular storage organ for urine. Urine drains from the bladder through a second tube called the **urethra**.



Make sure you check your spelling: ureter and urethra are easy to muddle and correct spelling is essential to ensure the meaning is not lost….

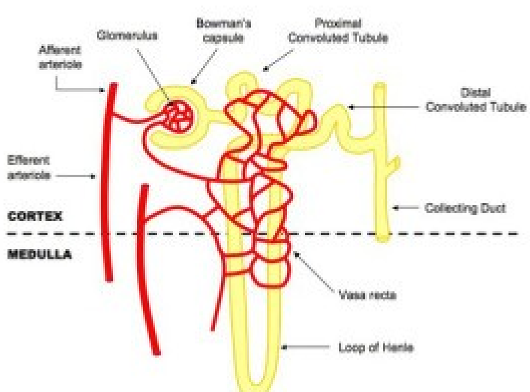
How is urine made in the kidney?

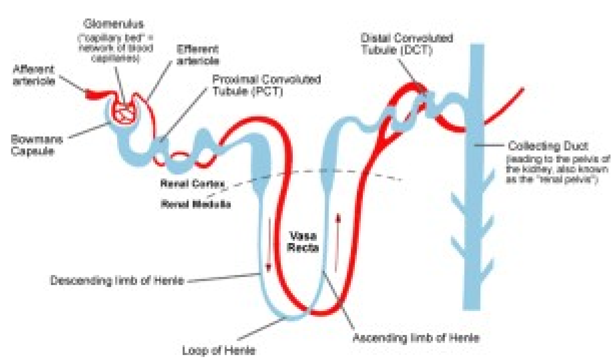
Well that's the big question for this post. How does the kidney start with blood and produce a very different liquid called urine from it….. Urine is basically made of water, dissolved urea and a few salts.



STRUCTURE OF KIDNEY:

There are three regions visible in a kidney: an outer **cortex**, an inner **medulla** which is often a dark red colour due to the many capillaries it contains, and a space in the centre called the **renal pelvis** that collects the urine to transfer it into the ureter. Blood enters the kidney through the large **renal artery** and deoxygenated blood containing less urea leaves the kidney in the **renal vein**.But there is no way from looking at the gross structure of the kidney that you could ever work out how the Dickens it produces urine. This requires careful microscopic examination of the kidney. Each kidney contains about a million tiny microscopic tubules called **nephrons**. The nephron has an unusual blood supply and an understanding of what happens in different regions of the nephron allows an understanding of how urine is made to be built up.



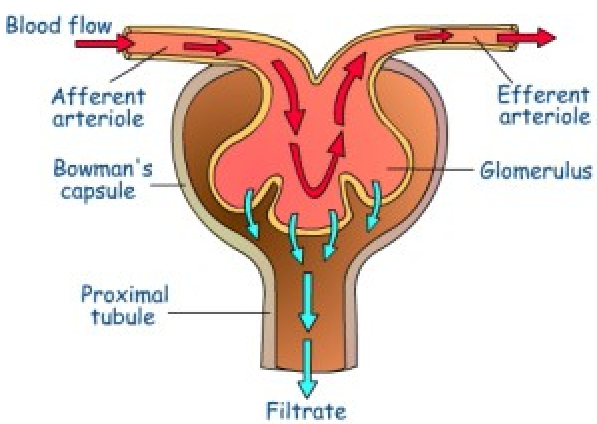


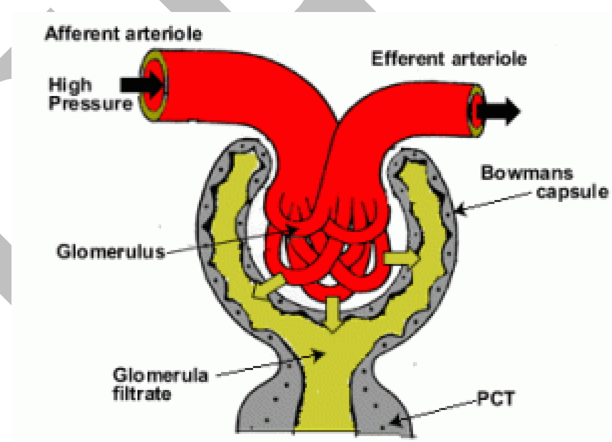
The nephron is the yellow tubule in the diagram above. It starts in the cortex with a cup-shaped structure called the **Bowman's capsule**. This cup contains a tiny knot of capillaries called the **glomerulus**. The Bowman's capsule empties into the second region of the nephron which is called the **proximal convoluted tubule**. The tubule then descends into the medulla and out again in a region called the **Loop of Henle**. There is then a second convoluted region called the **distal convoluted tubule** before the nephron empties into a tube called a**collecting duct.** The collecting ducts carry urine down into the renal pelvis and into the ureter.

Stages in the Production of Urine

1) Ultrafiltration

Blood is filtered in the kidney under high pressure, a process called **ultrafiltration**. Filtration is a way of separating a mixture of chemicals based on the size of the particles and this is exactly what happens to the blood in the kidney. Red blood cells, white blood cells and platelets are all too large to cross the filtration barrier. Blood plasma (with the exception of large plasma proteins) is filtered from the blood forming a liquid called **glomerular filtrate**. The kidneys produce about 180 litres of glomerular filtrate per day.





Ultrafiltration happens in the glomerulus and the glomerular filtrate (GF) passes into the Bowmans capsule. The high pressure is generated by the blood vessel that takes blood into the glomerulus (afferent arteriole) being much wider than the blood vessel that takes blood out of the glomerulus (efferent arteriole). The plasma of blood (minus the large plasma proteins) is squeezed out of the very leaky capillaries in the glomerulus and into the first part of the nephron.

What's in Glomerular Filtrate?

- *water*
- *glucose*
- *amino acids*
- *salts*
- *urea*

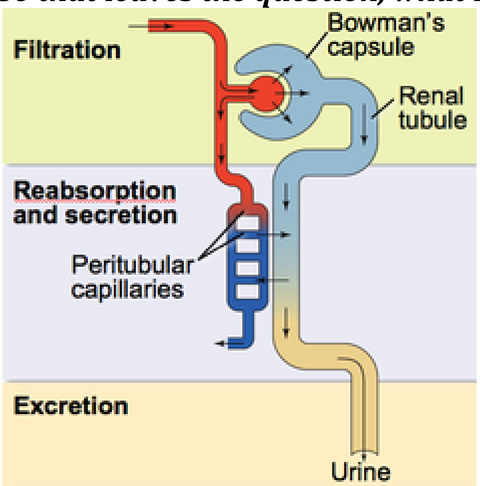
As well as containing urea, water and salts, glomerular filtrate also contains many useful molecules for the body (glucose and amino acids for example) so these have to be collected back into the blood in the second stage.....

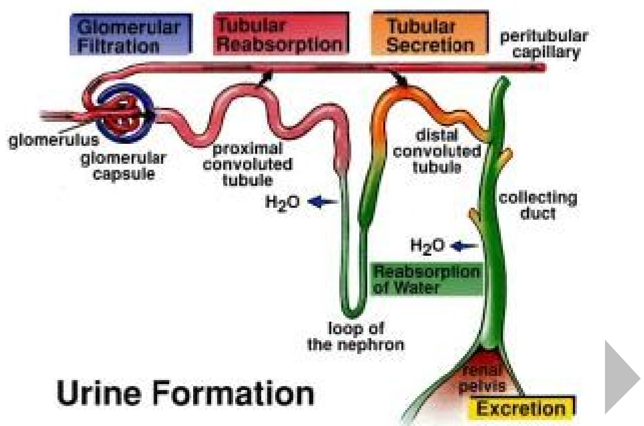
2) Selective Reabsorption

The useful substances in the glomerular filtrate are reabsorbed back into the blood. This can be by osmosis (for water) or by active transport (glucose and amino acids).

All of the glucose and all of the amino acids in the GF are **reabsorbed** in the **proximal convoluted tubule** by active transport. Remember active transport can pump substances against the concentration gradient using energy from respiration. Almost all the water in GF is reabsorbed by osmosis in the proximal tubule too.

So that leaves the question, what is the rest of the nephron doing…?





Well this is where it gets much more complicated…… Extra urea and salts can be secreted into the nephron at certain points along the tubule. The Loop of Henle allows the body to produce a urine that is much more concentrated than the blood plasma. And much of the distal tubules and collecting ducts are used for the second function of the kidney: **homeostasis.**But you will have to wait until my next post to find out how the kidney fulfils this crucial second function… Please add comments or questions to this post – I really value your feedback… Tell me what is unclear and do ask questions….

ENDOCRINE SYSTEM:

The endocrine system consists of a group of glands and organs that regulate and control various body functions by producing and secreting hormones. Hormones are chemical substances that affect the activity of another part of the body. In essence, hormones serve as messengers, controlling and coordinating activities throughout the body. To control endocrine functions, the secretion of each hormone must be regulated within precise limits. The body is normally able to sense whether more or less of a given hormone is needed.

Many endocrine glands are controlled by the interplay of hormonal signals between the hypothalamus, located in the brain, and the pituitary gland, which sits at the base of the brain. This interplay is referred to as the hypothalamic-pituitary axis. The hypothalamus secretes several hormones that control the pituitary gland.

The pituitary gland, sometimes called the master gland, in turn controls the functions of many other endocrine glands. The pituitary controls the rate at which it secretes hormones through a feedback loop in which the blood levels of other endocrine hormones signal the pituitary to slow down or speed up.

Functions of the endocrine system

Some of the roles of the endocrine system include:

- Growth
- Repair
- Sexual reproduction
- Digestion
- Homeostasis (constant internal balance).

The main glands and organs of the endocrine system include:

- **Pituitary gland** – is inside the brain. It oversees the other glands and keeps hormone levels in check. It can bring about a change in hormone production somewhere else in the system by releasing its own 'stimulating' hormones. The pituitary gland is also connected to the nervous system through part of the brain called the hypothalamus. The hormones released by the pituitary gland are gonadotropins (LH and FSH), growth hormone (GH), thyroid stimulating hormone (TSH), adrenocorticotropic hormone (ACTH), prolactin, antidiuretic hormone and oxytocin.
- **Thyroid gland** – sits in the neck at the front of the windpipe. It releases thyroid hormone (T4 and T3) which is required for metabolism and body homeostasis. It is controlled by TSH which is produced by the pituitary gland through a feed-back loop.
- **Parathyroid gland** – there are usually four parathyroid glands which lie alongside the thyroid gland. The parathyroid gland is involved in calcium, phosphate and vitamin D regulation.
- **Adrenal glands** – there are two adrenal glands which sit on top of each kidney. They make a number of different hormones. The outside part of the gland (adrenal cortex) makes cortisol, aldosterone and sex hormones. The centre of the adrenal gland (adrenal medulla) makes adrenaline. Adrenaline is an example of a hormone that is under the control of the nervous system.
- **Pancreas** – an organ of digestion which is inside the abdomen. It makes insulin, which controls the amount of sugar in the bloodstream. It also makes other hormones such as glucagon and somatostatin.
- **Ovaries** – are inside the female pelvis. They make female sex hormones like oestrogen.
- **Testes** – they hang in the male scrotal sack. They make male sex hormones like testosterone.

Control of Endocrine Activity

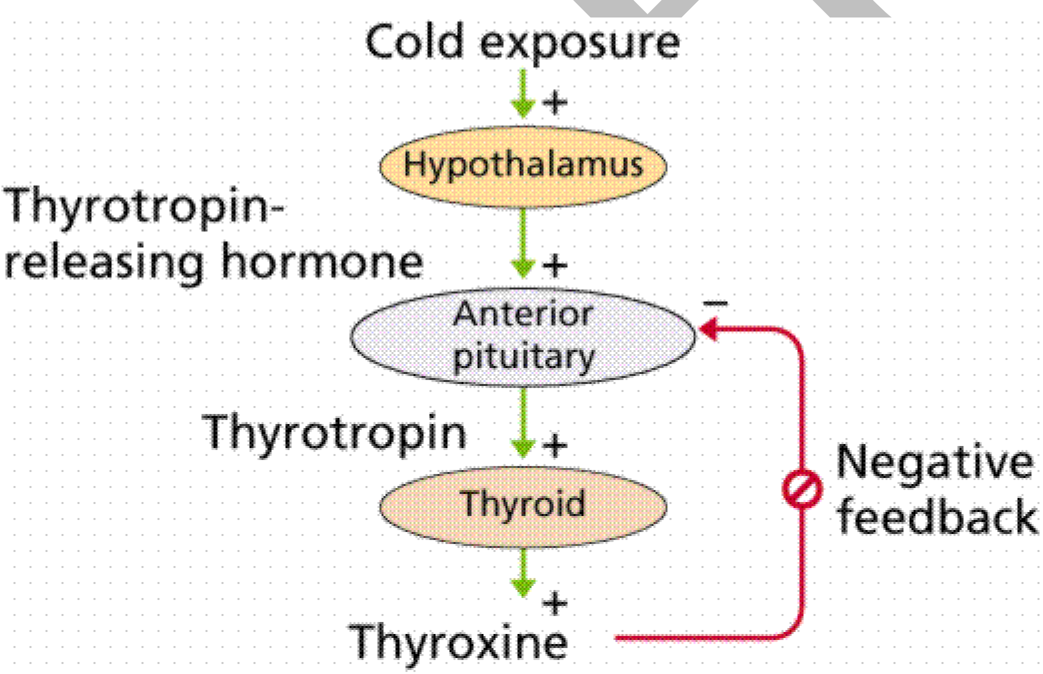
The physiologic effects of hormones depend largely on their concentration in blood and extracellular fluid. Almost inevitably, disease results when hormone concentrations are either too high or too low, and precise control over circulating concentrations of hormones is therefore crucial.

The concentration of hormone by target cells is determined by three factors:

- *Rate of production:* Synthesis and secretion of hormones are the most highly regulated aspect of endocrine control. Such control is mediated by positive and negative feedback circuits
- *Rate of delivery:* An example of this effect is blood flow to a target organ or group of target cells - high blood flow delivers more hormone than low blood flow.
- *Rate of degradation and elimination:* Hormones, like all biomolecules, have characteristic rates of decay, and are metabolized and excreted from the body through several routes. Shutting off secretion of a hormone that has a very short halflife causes circulating hormone concentration to plummet, but if a hormone's biological halflife is long, effective concentrations persist for some time after secretion ceases.

Endocrine Systems and Feedback Cycles

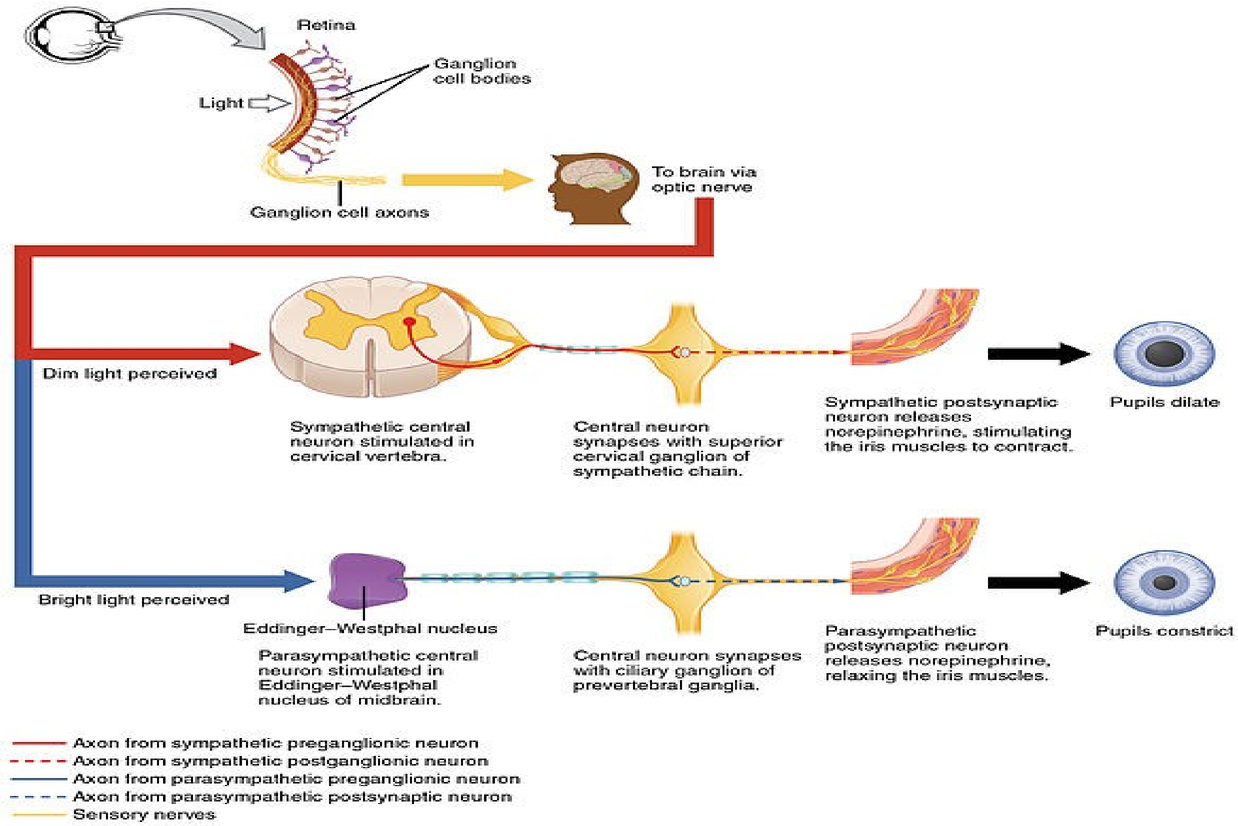
The endocrine system uses cycles and negative feedback to regulate physiological functions. Negative feedback regulates the secretion of almost every hormone. Cycles of secretion maintain physiological and homeostatic control.



The pituitary gland is located in a small bony cavity at the base of the brain. A stalk links the pituitary to the hypothalamus, which controls release of pituitary hormones. The pituitary gland has two lobes: the anterior and posterior lobes. The anterior pituitary is glandular. The hypothalamus contains neurons that control releases from the anterior pituitary. Seven hypothalamic hormones are released into a portal system connecting the hypothalamus and pituitary, and cause targets in the pituitary to release eight hormones.

Hypothalamus receptors monitor blood levels of thyroid hormones. Low blood levels of Thyroid-stimulating hormone (TSH) cause the release of TSH-releasing hormone from the hypothalamus, which in turn causes the release of TSH from the anterior pituitary. TSH travels to the thyroid where it promotes production of thyroid hormones, which in turn regulate metabolic rates and body temperatures.

PUPIL CONTROL SYSTEM:



The pupil is the opening in the center of the iris (the structure that gives our eyes their color). The function of the pupil is to allow light to enter the eye so it can be focused on the retina to begin the process of sight.

Typically, the pupils appear perfectly round, equal in size and black in color. The black color is because light that passes through the pupil is absorbed by the retina and is not reflected back (in normal lighting).

If the pupil has a cloudy or pale color, typically this is because the lens of the eye (which is located directly behind the pupil) has become opaque due to the formation of a cataract. When the cloudy lens is replaced by a clear intraocular lens (IOL) during cataract surgery, the normal black appearance of the pupil is restored.

There's another common situation when the pupil of the eye changes color — when someone takes your photo using the camera's flash function. Depending on your direction of gaze when the photo is taken, your pupils might appear bright red. This is due to the intense light from the flash being reflected by the red color of the retina. [Read more about red eyes in photos and how to avoid them.]

Pupil Function

Together, the iris and pupil control how much light enters the eye. Using the analogy of a camera, the pupil is the aperture of the eye and the iris is the diaphragm that controls the size of the aperture.

The size of the pupil is controlled by muscles within the iris — one muscle constricts the pupil opening (makes it smaller), and another iris muscle dilates the pupil (makes it larger). This dynamic process of muscle action within the iris controls how much light enters the eye through the pupil.

In low-light conditions, the pupil dilates so more light can reach the retina to improve night vision. In bright conditions, the pupil constricts to limit how much light enters the eye (too much light can cause glare and discomfort, and it may even damage the lens and retina).

Pupil Size

The size of the pupil varies from person to person. Some people have large pupils, and some people have small pupils. Also, pupil size changes with age — children and young adults tend to have large pupils, and seniors usually have small pupils.

Generally, normal pupil size in adults ranges from 2 to 4 millimeters (mm) in diameter in bright light to 4 to 8 mm in the dark.

In addition to being affected by light, both pupils normally constrict when you focus on a near object. This is called the accommodative pupillary response.