Mammary Gland

- Position and number of mammary glands vary with species.
- Number of glands (and therefore individual teats) varies with the number of young reared.
- The mammary gland and teat of domestic animals is collectively called *udder*.
- Location of mammary gland is described as **inguinal, abdominal or thoracic**.
    - Goat, ewe, mare have 2 glands and 2 teats - 1 teat opening or *streak canal* / gland (mare-2 opening / teat).
    - Cow – 4 glands and 4 teats
    - Sow - 12 to 14 teats (usually) which are small, long and cylindrical /2 inguinal pairs, 3 abdominal pairs, 2 thoracic pairs (thoracic are most productive) - 2 (or 3) teat openings.
    - Cat-8 teats (usually)/1 inguinal pair, 1 abdominal, 2 thoracic pairs (abdominal are most productive)-3 teat openings on tip of teat. Additional sinus opens on the side of the teat.
    - Bitch-10 teats (usually)/1 inguinal pair, 2 abdominal pairs, 2 thoracic pairs (abdominal are most productive)-similar to cat. About 12 teat openings situated on tip of teat.
- The mammary glands of cattle, sheep, goat, horse and whales are located in the *inguinal region*
- Those of primates and elephants in the *thoracic region*
- Those of pigs, rodents and carnivores along the ventral surface of *both the thorax and abdomen*
- **The mammary glands are greatly modified and enlarged sweat glands**.

- In the inactive mammary gland, the interstitial spaces between lobes and ducts are filled mainly with fat. There are a few alveoli present compared to those in the lactating gland and the ducts and lobes of the gland are smaller than when the gland is in its active phase.
- During early pregnancy, the epithelial cells of the glandular tissue proliferate rapidly to form the buds which eventually enlarge to form the alveoli.
- As pregnancy develops, the fat and connective tissue between lobes and ducts are replaced by secretory tissue.
- **The mammary gland's milk-secreting structures are *alveoli* which empty directly into the larger ducts and also directly into the gland cistern and the teat cistern.**
- A **circular muscle around the streak canal functions as a sphincter which helps to retain milk** in the gland cistern.
- At the junction of the streak canal and the teat cistern, the ***rosette of Furstenberg*** is present, which is a double layered epithelial lining that helps to retain milk in the teat.
- A group of alveoli surrounded by a connective tissue septum forms a distinct unit called ***lobule***.
- A group of lobules surrounded by a large amount of connective tissue form a ***lobe***.
- The lobule empty into small ducts called the *intralobular duct* within the lobule. It drains into a central collecting space from which the *interlobular duct* emerges.
- Within the lobe, the interlobular ducts unite to form a single *intralobar duct*. The interlobar duct may enter into the gland cistern directly or it may join with one or more other interlobar ducts before entering into the *gland cistern*. More amount of milk is stored in ducts than in cistern. Contractile

myoepithelial cells also called as basket cells which resemble the smooth muscle fibres surround the alveoli and ducts. On contraction of these cells the milk is letdown from the alveoli and ducts.

- **Approximately 11% of mammary development occurs before pregnancy, 41% during pregnancy and the reminder takes place during early lactation**.

Surface anatomy of the bovine udder

- The appearance of the udder varies depending on maturity and functional status.
- In dairy cows udder is very large and can weigh up to 60 kg.
- **The udder is divided into two halves, each half having two quarters, thus four quarters correspond to the four glands - each gland bearing a principle teat**.
- **A median intermammary groove marks the division of the udder into right and left halves**.
- The division between fore and hind quarters is less distinct The structures supporting the udder are:

1. Skin - mobile, flexible and covered in fine hairs. Skin does not provide any mechanical support to udder.
2. **Suspensory apparatus** - The right and left halves of the udder are separated by median suspensory ligament containing elastic tissue. Lateral suspensory ligaments composed of non elastic fibrous strands give rise to numerous lamellae that penetrate into the gland and continue with interstitial tissue.
3. Right and left medial laminae are separated by a layer of loose areolar connective tissue allowing easy surgical division of one side of the udder from another.

Blood supply to udder

- Caudal aorta gives off right and left common iliac arteries that branch to external iliac and pudic arteries, the latter gives rise to cranial and caudal mammary arteries to supply the cranial and caudal parts of the udder respectively The major drainage route from the udder follows the same course as arteries – from mammary veins to external pudic to external iliac veins that join the caudal vena cava.
- Another potential drainage route from udder is through *subcutaneous abdominal veins* to cranial venacava. In lactating animals, a large quantity of blood is drained via this route In dairy cow the ratio of volume of blood flow through mammary gland to volume of milk produced is about 670:1

Nerve supply The udder is supplied with both sensory and motor nerves. The sensory nerves are important for the milk ejection reflex (does not require efferent nerve). The motor nerves to udder have both sympathetic and parasympathetic innervations. These nerves do not influence the rate of milk secretion or milk composition

LACTATION

- *Lactation* refers to the combined process of milk secretion and removal.
    - M*ammogenesis* is development of mammary gland.
    - *Lactogenesis*is initiation of milk secretion.
    - *Galactopoiesis*is maintenance of milk secretion.

MAMMOGENESIS

- At about 35 days age of embryo in bovines, a mammary line forms from the stratum germinativum parallel to ventral midline on either side of the ventral line.
- At birth, the udder has teat and gland cisterns but ducts are developed to a limited extent. Most of the udder structure is formed of adipose and connective tissues.
- From birth to puberty, the mammary growth rate is similar to the whole body growth rate (*isometric growth*); increase in size at this time is due to connective tissue and fat.
- At the time of puberty, mammary parenchyma begins to grow at a much faster rate than whole body growth (*allometric growth)*. This allometric growth again occurs after conception up to early parturition.
- During each oestrous cycle, the mammary gland is stimulated by oestrogen from ovary and GH and PRL from adenohypophysis; the mammary growth by oestrogen involves ductular development.
- Most of the mammary growth occurs during pregnancy and this growth occurs in an exponential manner. Alveolar secretory cells increase in number with extensive ductular development; alveoli are formed. Estrogen with GH and adrenal steroids are responsible for proliferation of duct system and progesterone along with PRL is responsible for the development of alveoli.

About 10% (cow) to 50% (rats) growth of mammary gland occur during early lactation involving alveolar cell proliferation.

- The ratio of progesterone to estrogen as well as the absolute amounts of each is important for complete development of the mammary gland.
- Cessation of suckling or milking brings about mammary involution with decrease in number of epithelial cells and secretory activity. Myoepithelial cells remain. Adipose cells increase. If the dry period occurs at later stages of pregnancy the decrease in secretory epithelial cells is reduced. Too short a dry period (<6 weeks) reduce the increase in mammary cells that occur during subsequent lactation.

HORMONAL CONTROL OF MAMMARY GLAND DEVELOPMENT

- FSH and LH, the hormones of adenohypophysis control the ovarian hormones, oestrogen and progesterone, and their mammogenic effects in the mammary gland.
- Placental lactogen also functions as mammotrophic hormone.
- The adenohypophysis influences the mammary gland directly with prolactin and STH and indirectly by its control of the hormones of the thyroid and adrenal cortex.

Hormones involved in mammary gland growth and functions

Endocrine organ	**Hormone**	**Function related to mammary gland**
Anterior pituitary	FSH	Oestrogen secretion from ovarian follicles
	Prolactin	Mammary growth; initiation and

		maintenance of lactation
	GH	Stimulates milk production
Posterior pituitary	Oxytocin	Milk ejection
Thyroid gland	T3, T4	Stimulates O2 consumption, protein synthesis and milk yield
	Calcitonin	Calcium and phosphorus metabolism
Adrenal cortex	Glucocorticoids	Initiation and maintenance of lactation
Adrenal medulla	Epinephrine, norepinephrine	Inhibition of milk ejection
Ovary	Estradiol	Mammary duct growth
	Progesterone	Mammary alveolar –lobule growth, inhibition of lactogenesis
Placenta	Estradiol	Mammary duct growth
	Progesterone	Mammary alveolar –lobule growth, inhibition of lactogenesis
	Placental lactogen	Mammary growth

Lactogenesis

- It is the process of differentiation in which the mammary alveolar cells acquire the ability to secrete milk.
- Lactogenesis includes two stages:
- Stage I occurs before parturition in which alveolar cells differentiate and acquire a limited capacity for milk secretion
- Stage II begins shortly before parturition and continues for several days postpartum in which the alveolar cells are able to secrete copious amount of milk components.
- Many hormones are required for lactogenesis:
- Progesterone of pregnancy blocks lactogenesis. Its secretion starts to decline during late pregnancy and mammary gland becomes responsive to the lactogenic hormones – insulin, glucocorticoids and prolactin.
- Mammary alveolar differentiation is stimulated by these lactogenic hormones and secrtory apparatus develop in alveolar cells
- The lactogenic hormone insulin stimulate gene expression in alveolar cells and thus required for protein synthesis and induces sensitivity to other hormones
- Glucocorticoids induce differentiation in alveolar cells for casein synthesis
- Prolactin stimulates transcription of genes for milk proteins
- Progesterone inhibits prolactin receptor synthesis and prolactin stimulation of milk protein synthesis. It also inhibits the PRL effect on α-lactalbumin (an enzyme component of lactose synthase) synthesis.
- Prepartum milking can initiate lactation – neural impulse to hypothalamus initiate PRL and ACTH secretion leading to mammary cell secretion.

Galactopoiesis

- It is the maintenance of lactation.
- It involves maintaining the alveolar cell numbers and function
- After parturition, milk yield increases in cows, which reaches a maximum in 2 to 8 weeks and then gradually declines, which is due to decline in the number of secretory cells.
- If milk is not removed frequently from the mammary gland, synthesis of milk will not persist even with adequate hormonal levels.
- Maintenance of lactation requires GH, ACTH (glucocorticoids), insulin, thyroid hormones, prolactin and PTH.
- The thyroid hormones influence the milk synthesis and duration of secretion;
- Insulin is required for glucose uptake in the mammary gland;
- ACTH maintains mammary cell numbers and alveolar cell metabolic activity.
- Suckling stimulates the prolactin secretion at a high level along with the other galactopoietic hormones from the adenohypophysis. PRL has an important role in milk secretion; it is released during suckling or milking and peak values are reached 30 min after initial stimulus.

INDUCTION OF LACTATION

1. Lactation can be artificially induced in dairy cattle by the use of variety of hormones when the mammary gland contains sufficient numbers of alveolar cells.
2. **Subcutaneous injection** of a total daily dose of **0.1-mg/kg body weight of oestradiol-17** and **0.25mg/kg body weight of progesterone** dissolved in **100% ethanol** in divided dose at **12 hours interval for 7 days will initiate lactation in about 60 to 70% of heifers and cows.** The percentage of success rate increases to 100% if **5mg of reserpine (a tranquilizer) is administered on day 8, 10, 12 and 14 to increase the prolactin level in these animals**. Lactation starts between days 14 and 21 after initial injections of estradiol-17 and progesterone.
3. ACTH or glucocorticoids in large doses inhibit lactation in ruminants and rats
4. GH produces a dose-dependent increase in milk yield in dairy cows. The increase in milk yield by GH is produced by ***nutrient*** **partitioning from body tissue requirements to milk synthesis**.
5. Recombinant bovine GH (bST) has been employed to increase milk yield in lactating animals. Injection of **GH three times a week stimulates short term increase 13 to 18% in the milk production and 15% feed efficiency, whereas reduces the feed intake by 29% in high producing cows.**
6. Injection of **low dose of synthetic glucocorticoids** stimulates milk yield by 14 to 18%.
7. **Iodocaesin and L-thyroxine have been used to induce milk production.** Iodinated casein, (0.5 percent crystalline thyroxine) has been fed to dairy cattle at a rate of **1 to 1.5 g per 45kg of body weight daily**, resulting in an increase in milk production of **10 to 30 per cent**.

8. Extra feed must be provided to prevent weight loss and milk production declines abruptly following withdrawal of thyroproteins.
9. **Thyroproteins increase the need for more nutrients, reduces body weight and interferes with the ability to withstand thermal stress.**
10. Thyroprotein fed to dairy cows at the **peak of lactation stimulates milk production by about 10%, whereas during declining phase of lactation it stimulates the milk production by 15 to 20%**. Usually a greater increase in milk production occurs in high producing cows and older cows. The maximal increase usually occurs during the first 60 days of thyroprotein feeding. However, beneficial effects disappear within 2 to 4 months.

MILK EJECTION (MILK LET-DOWN)

1. Milk ejection or milk let down can be achieved by the contraction of the myoepithelial cells when stimulated by oxytocin.
2. Removal of milk is a *neuroendocrine reflex*.
3. This process involves activation of neural receptors in the skin of the teat.
4. Mechanical stimulation of teats like milking or suckling the teats by the young initiates the neural reflex which travels from the teats to spinal cord to hypothalamus to posterior pituitary, where oxytocin is released into the blood. Oxytocin reach the myoepithelial cells of the mammary alveoli and contract them expelling millk from the alveoli
5. The milk ejection reflex can also be conditioned to stimuli associated with milking routines such as feeding, sight of calf and washing the udder
6. The milk ejection reflex is inhibited by emotional states like loud noise, pain, excess muscular activity and stress which stimulates the sympathetic nervous system and causes the release of epinephrine which blocks the reflex.

FACTORS AFFECTING LACTATION

1. **Energy:**
   i. It is **essential for growth and lactation**
   ii. **It is the most limiting factor because** it is necessary for metabolism of all the other nutrients.
   iii. Adequate supply of energy at the proper time and amount is important in lactation; inadequate energy at the beginning of lactation, when demands are greatest will decrease milk production to a greater extent than energy deficiency at the latter part of lactation.
   iv. **Cows at peak lactation are in negative energy balance**, **which is desirable for efficient milk production because body fat reserves are used to meet energy requirements.**
2. Changes in protein intake have little effect on milk yield and composition especially milk protein.
3. **Milk fat content is influenced by heredity** and it is the **most variable content of milk**.
   i. Milk yield and fat are influenced by diet;
   ii. Diets which produce low ruminal acetate/ propionate ratio (high concentrate diets) causes low amount of milk fat.
   iii. Fat content of the diet does not influence milk fat content.
   iv. A minimum of 19% fibre in the diet of lactating animals is necessary for optimum rumen fermentation and to maintain milk fat level.
   v. Milk fats are highly saturated and to increase polyunsaturated fatty acid content of milk fat, vegetable oils can be fed in a protected form.
4. **Stage of lactation influences the milk yield and composition**.
5. **Milk yield continues to increase from parturition for about 4 to 8 weeks and after a peak is attained, milk yield gradually decline.**

6. **Fat, protein and lactose contents in milk increase slightly as lactation progresses.**
7. **Pregnancy reduces milk yield**. Ideal dry period recommended for cows is 6 to 8 weeks; shorter or longer dry period will reduce milk yield of the subsequent lactation.
8. Milk yield increases up to about eighth year of age of cows, which then decreases;
9. **Larger cows produce more milk than smaller ones but yield does not vary in direct proportion to body weight**.
10. **Milking twice-daily increases yield by about 40% than once daily milking**;
11. milking three times daily yields 5 to 20% more milk than twice daily yield;
12. four times a day milking may produce another 5 to 10% more milk.
13. The factors that contribute to more milk with increasing frequency of milking are – less intra mammary pressure, increased stimulation by hormones (PRL), less negative feed back inhibition of milk constituents on cellular synthesis.
14. **Environmental temperature alters milk yield and composition by affecting BMR, food intake, digesta passage, and maintenance requirements of nutrients; this effect depends on breed** – Bosindicus tolerate heat better than *Bostaurus.*
15. Holsteins are more tolerant for low temperature and jerseys are more tolerant of high temperature

BIOSYNTHESIS OF MILK

1. **Mammary epithelial cells** take precursors for milk synthesis from blood through the basal and lateral membrane and discharge the milk through the apical membrane into the lumen of alveolus.
2. **Mammary alveolar cells synthesize fats, proteins and carbohydrates**
3. Fat first accumulate in the basal cytoplasm of the cell, then move to the apex where the droplets protrude into the alveolar lumen.
4. Bovine milk fat consists of **large proportions of short-chain fatty acids (C4-C16)**.
5. The fatty acids and glycerol are synthesized in the cytoplasm and the triglycerides are formed in the endoplasmic reticulum of the mammary epithelial cells.
6. The fatty acids are synthesized from three major sources
    a. **Acetate and β-hydroxy butyrate–primary source formed in rumen**, transported to mammary gland. Acetate contributes to **C4 toC14 fatty acids of milk**. In non ruminants acetyl CoA from glucose is the major source for milk fatty acids
    b. Fatty acids of the triglycerides present in the circulatory system as **low-density lipoproteins** and **chylomicrons** are another source. They contribute **fatty acids C16 and above**. Half of milk fatty acids are derived directly from blood triglycerides
    c. Cytoplasmic acetyl CO-A from glycolysis and TCA cycle is the third source
7. Glycerol for triglyceride synthesis is derived from glycerol 3-phosphate of glycolytic pathway or from lipolysis of triglycerides in the mammary gland.
8. Major **milk proteins are caseins (α, β and κ), β-lactoglobulin and α-lactalbumin**.

9. *Lactoferrin*and lysosomal enzymes are other proteins present in milk.
10. Milk immunoglobulins are derived from blood as preformed proteins.
11. Milk proteins are synthesized on the endoplasmic reticulum; the casein molecules pass to the golgi apparatus for phosphorylation, forms micelles within the golgi vesicles.
12. Several genetic variants of milk proteins occur; the genetic polymorphism of milk proteins are useful for genetic identity of the animal
13. ***Lactose* , a disaccharide composed of glucose and galactose is found exclusively in milk**. It is synthesised from two molecules of the precursor glucose. One glucose is converted to galactose; **lactose synthase**catalyses the reaction between glucose and galactose to form lactose.
14. The ***lactose synthase* is composed of two subunits–galactosyltransferase and *α-lactalbumin***.
15. Lactose is synthesized within golgi vesicles, released in conjunction with milk protein. The golgi vesicles fuse with the cell membrane and release protein and lactose by exocytosis.
16. During pregnancy progesterone blocks the secretion of α-lactalbumin, a milk whey protein, which is also an enzyme needed for synthesis of lactose.
17. **The major minerals in milk are Ca, P, K, Cl, Na and Mg and they are derived from blood.**
18. **Vitamins cannot be synthesized by the mammary gland and they are derived from blood**.

COLOSTRUM

- Colostrum, the **first milk produced upon delivery of the newborn**,
- It is an important **source of essential nutrients** to off spring.
- Contains **lymphocytes and monocytes to protect against exposure to infection**
- Contains a greatly increased amount of protein, especially casein and globulins – the globulins are mainly immunoglobulins and in cow IgG is predominant.
- Rich in vitamin A, E, carotene and riboflavin.
- However, lactose, vitamin D and iron are all low compared to normal milk.
- Colostrum has **laxative effect and helps to expel meconium from foetal digestive** tract.
- Neonates have a limited time (24 – 36 h) in which the immunoglobulins (γ-globulins) can be absorbed through the gut. Thus, feeding of colostrums within this period is important to ensure the presence of antibodies in the newborn. In domestic animals this Ig transfer is important for the neonate immunity because of poor placental transfer of antibodies.
- Colostrum is formed in the mammary gland before parturition and it is the first milk secreted after parturition.

FUNCTIONS OF MILK

- Milk is essential for growth and development of young animal
- It provides energy (lactose and fat) and amino acids to the young ones
- Provides antibodies, vitamins and minerals

- **Milk Composition**

Animal	Water	Fat	Protein	Lactose	Ash
Buffalo , water	82.8	7.4	3.8	4.8	0.8
Camel	86.5	4.0	3.6	5.0	0.8
Cow (Bos Taurus)	87.3	3.9	3.2	4.6	0.7
Cow (Bosindicus)	86.5	4.7	3.2	4.7	0.7
Dog	76.4	10.7	7.4	3.3	1.2
Goat	86.7	4.5	3.2	4.3	0.8
Horse	**88.8**	1.9	2.5	6.2	0.5
Pig	81.2	6.8	4.8	5.5	1.0
Rabbit	67.2	15.3	*13.9*	2.1	1.8
Sheep	82.0	7.2	4.6	4.8	0.9

- Composition varies greatly among species
- Protein varies from less than 1 to 14%, fat from traces to more than 50%, lactose form traces to 7%, ash from 0.2 to 2 % energy from 40 to 330 kcal/100g.
- Rapidly growing species like rat and rabbit have high protein content.
- Among and within breeds of cattle there are major differences in milk composition which are influenced by genetic selection.

GROWTH

- Growth is a biological synthesis of new biochemical units. It is the aspect of development concerned with increase in living substance or protoplasm which includes one or all of the three processes,
- Cell multiplication, e.g. cleavage of egg into daughter cells, formation of blood corpuscles, monocytes, hair follicles, and ectoderm cells.
- Cell enlargement e.g. nervous tissue and skeletal tissue
- Incorporation of material taken from the environment e.g. proteins and minerals.

THEORIES OF GROWTH

The theories of growth are based on

- Development (Needham)
- Growth (Hammet, Brody and Maynard)

Needham's theory of Development

- Development refers to the directive co¬ordination of the diverse processes into an adult in an organized heterogeneity.
- Some types of growth are not developmental e.g. teeth development, teratoma (jumbles of hair), cancerous growth, growth of tissue cultures in vitro due to self-multiplication without directive significance etc.

Needham subdivided differentiation into

- Increase in the number of kinds of cells
- Increase in the morphological heterogeneity
- Cell multiplication

He subdivided growth into

- Intussusception/increase in size of cells
- Accretion/increase in the amount of non-living matter.

According to him, metabolism includes

- Respiration (oxidation)
- Fermentation (glycolysis)
- Catabolism of protein
- Catabolism of fat
- Chemical activity as pigment formation, glycogen synthesis etc.

Hammet's theory of growth:

- Growth is a coordinated expression of incremental and developmental factors and functions.

Brody's theory of growth:

- Accoding to him, growth is a relatively irreversible change in the measured dimension i.e. increase in size and weight.
- Irreversibility changes exclude fluctuating feed supply with consequent fattening and leaning with gestation, lactation etc.

Maynard's theory of growth:

- He differentiated true growth and false growth (Deposition of fat in the adipose tissue).
- True growth is increase in the size and weight of the structural organs and tissues such as muscle, bone except adipose tissue.
- Chemically true growth is characterized by increase in protein and mineral deposition in the body.
- Increase in weight due to fat deposition and water accumulation is not considered as true growth.

CELL AS A UNIT OF GROWTH

- Growth process involves both increase in the size of cells called as hypertrophy and increase in the number of the body cells called as hyperplasia. The process by which a single cell grows from within cell is called as intussusception.
- During hyperplasia there is an increase in the DNA and most of the cells contain only one nucleus and each nucleus contains the same amount of DNA. The amount of DNA present in a tissue can be used as an index of number of cells present in the tissue.
- During hypertrophy cell size increases but DNA content remains constant. In most of the cells increase in the size of cells causes an increase in cell proteins. Hence the protein/DNA ratio is an index of cell size and growth. RNA/protein ratio indicates capacity for protein synthesis.
- The protein/DNA ratio varies with tissue, age, species and other factors. Under optimal conditions and nutrition protein/DNA ratio is maximum.
- During a short period of starvation tissue protein level decreases while DNA remains constant.
- When feeding is resumed, cellular protein level increases rapidly to reach the previous protein/DNA ratio. This rapid rate of growth after a period of starvation is called as compensatory growth. This type of growth occurs when part of an organ stops growing or when a part of it is experimentally removed.
- During the embryonic life all the cells of the body undergo hyperplasia and hypertrophy, whereas in adults, 3 different types of cell show proliferation
    - Permanent cells or static organs
        - These cells lose their mitotic activity after differentiation and stop dividing early in their prenatal life and their number remains constant e.g. muscle cells, nerve cells.

- o Stable cells or expanding organs
- These cells undergo mitotic activity and continue to divide and increase in their number during their growth period but they stop dividing in the adult. Their number is fixed and the cells have prolonged longevity, e.g. all exocrine glands, lungs, kidneys, and most of the organs of the body.
- o Labile cells or renewing organs
- These cells continue to divide through out the life of the animal, e.g. blood cells, epithelial cells etc.

PERIODS OF GROWTH

- Growth can be divided into two periods
  - o Prenatal growth
  - o Postnatal growth

Prenatal Growth

- The period of growth between the time of fertilization and the birth of the young one is called prenatal growth. In poultry 21 days are required for the fertilized egg to become a fully functional chick, but in farm animals it takes a long time.
- A new individual arises from the union of a sperm and ovum, forming one cell with diploid number of chromosomes. The single fertilized cell divides as it passes down the oviduct but there is little increase in total size. In this cell division, the mother cell produces two daughter cells, which are capable of further division to form new cells.
- Somatic cells produced from cell division have a diminishing power to grow by hyperplasia. In highly differentiated cells, the power to produce is lost e.g., mature RBCs entering the circulation do not have nucleus and cannot divide and dies after about 120 days but the bone marrow cells produce the RBCs

continuously. But, the differentiated nerve or brain cells lose their ability to divide and there is no mechanism to create new cells.

- The developing fertilized egg undergoes a process of differentiation in which the mother cell produces different kinds of daughter cells like brain cells and heart cells is called cytogenesis or histogenesis . This process is irreversible in which the brain cells cannot form the egg cells. As the development of embryo proceeds many organs are formed and then differentiation ceases. The organization of various dividing cells into different organs each with a particular structure and function is known as morphogenesis or organogenesis. During morphogenesis, the differentiated cells synthesize new proteins and enzymes, which are specific for each tissue formed.
- Cleavage is the process by which a zygote or fertilized ovum subdivides into smaller cells called blastomeres. When a new embryo has divided into a ball of sixteen or more blastomeres (but has not yet formed layers of blastomeres) it is called a morula. The morula starts to form various organs from a clump of cells called the inner cell mass. The morula then forms itself into a layer of cells called the trophoblast surrounding a fluid filled space called the blastocoele. The trophoblast develops into the placenta and is lost at birth, whereas the inner cell mass develops into the embryo proper. The inner cell mass together with the trophoblast forms the blastocyst. The embryo developing from the inner cell mass becomes roofed over by amniotic folds that later fuse to form a complete layer- the amnion. The blastocyst then becomes a gastrula, which is successively and three layered. Ectoderm (primary outer), endoderm (inner) and mesoderm (middle) layers develop. These three primary germ layers give rise to the organs of the embryo.

i) The outermost layer (ectoderm) forms a mid dorsal ridge along the antero-posterior axis of the blastocyst quite early in the development. The innermost layer (endoderm) forms inner lining of gut, its glands and the bladder.

- This elongated ridge of neural ectoderm subsequently gives rise to brain, spinal cord and other derivatives of the nervous system. Ectodermal cells lateral to the neural ectoderm develop into the skin and its derivatives such as mammary glands, hair and hoofs.
- ii)
- iii) The mesodermal layer gives rise to muscles, bones, connective tissue and vascular systems.
- The outer (somatic) layer of the mesoderm gives rise to a series of somites (body segments) along each side of the spinal cord. In cattle, the differentiation of somites starts on 19th day of pregnancy the number of somites gradually increases to 25 on the 23rd day, 40 on the 26th day and 55 on the 32nd day. Number of somites can be used to determine the pre-natal growth.
-

Cell division is very rapid during the first few weeks after implantation than at any other time of life. The rat and rabbit conceptus grow to a weight of l g in 2 weeks, pig and cat in 4-5 weeks and in humans 8 weeks. The rate of growth after implantation determines subsequent growth in uterus. The human fetus remains in the uterus for about 280 days to have a birth weight of 3.4kg. The lamb is born with a birth weight of 4 kg, which is attained in about 148 days, and the foal reaches this weight at 160 days of conception.

FACTORS INFLUENCING PRENATAL GROWTH

Heredity

- The ultimate growth of fetus depends on its own genotype and that of its mother and littermates determine the ultimate size of the fetus. There are variations in the species, individuals, and breeds. The maternal contribution to variability in fetal size is greater than the paternal contribution.

Foetal hormones

- Several hormones are secreted by the fetal endocrine glands. The presence of a hormone does not necessarily indicate that it is actually secreted into the blood and plays a physiological role. As these hormones should have receptors on the target system to bring about any physiological actions.

Pituitary gland

- In some species like cow, mare, sheep and goats growth hormone is physiologically active wherein the young ones born are relatively mature with their eyes open and have the ability to stand up immediately after birth. These young ones are called as precocial young ones.
- In certain species like dogs and laboratory animals, the growth hormone produced by the fetal pituitary is physiologically inactive and the young ones born are immature with their eyes closed. Even though the fetal pituitary produces most of the hormones they are not important for fetal weight gain but mainly involved in fetal metabolism and parturition e.g. Cortisol.

Thyroid gland

- The fetus can synthesize and secrete its own thyroid hormone. This hormone is essential for morphogenesis, differentiation and development of nervous system in the foetus e.g. in the man and rats brain fails to develop when thyroxine is deficient.

Gonadal hormones

- The fetal gonadal hormones are involved in the development of both the sexes. In the males androgen produced by the fetal testes is important for the descent of the testes into the scrotum.

Size and age of the dam

- Foetal growth is directly related to the maternal size. Larger the maternal size, faster is the prenatal growth. Size of the dam plays an important role in spite of a large sire i.e. if the size of the dam is small the fetus size will also be small, e.g. mules and hinnies. The mule with a large horse as a dam is much larger in size than the ninny with the small donkey as a dam. Further the difference in size also depends on the length of the gestation period. A long gestation means more fetal growth than in species with a short gestation period.
- Age of the dam influences the size of the fetus. As the age of the dam increases the fetal size also increases. But in the aged and older animals the young born are small because of excessive internal fat deposition, which prevents the full expansion of the pregnant uterus.

Maternal nutrition during pregnancy

- The fetus is really privileged so far as nutrition is concerned.The fetus will continue to grow even if the dam is undernourished but will have a reduced growth rate and decreased birth weight. Under certain circumstances the weight of the fetus is proportional to the caloric intake of the mother, e.g. increased feeding of sheep during the later stages of gestation will have a marked effect on the birth weight of the fetus. Under nutrition or deficiency of vitamins and minerals will induce developmental abnormalities in the fetus.
- Poor nutrition of mother affects the glycogen content of the fetal muscle and liver. Fetal glycogen serves as a source of energy immediately after birth and normally builds up during later stage of pregnancy. So when the mother is poorly fed, poor synthesis of liver glycogen may be the cause of more neonatal mortalities.
- Restriction of diet of mother produces different effects in different organs of fetus. The nervous system skeletal and heart are least affected, whereas kidneys,

lung and muscles are moderately affected. The skin, thymus, spleen and liver are highly affected.

Litter size

• Increase in the litter size decreases the birth weight of the fetus, e.g. Inpolytocus species, increased litter size and in the monotocus species, multiple births reduces the rate of prenatal growth because of variations in the functions of the placenta and the duration of pregnancy.

Sex of the fetus

• Male fetuses generally grow at a faster rate and have a higher birth weight than the female fetuses. In case of twins the male is always heavier.

Placental size

• The placenta determines the prenatal growth, as it is being regarded as a fetal organ and the placenta transports all the nutrients, which reach the fetus. Growth rate of the fetus is directly proportional to the placental size. Smaller the placenta, smaller will be the fetus, the growth of the fetus will be retarded. Anatomically, placenta acts like a blood reservoir in the maternal circulation. Therefore, the blood flow to the uterus will be lower when there are several placentas in large litters than in a single litter. This will reduce the oxygen supply to at least the more distantly placed placentas. This will affect the growth of the fetus.

Ambient temperature

• It has a direct effect on the on the growth of the fetus. Either a high or low ambient temperature will reduce the fetal growth, e.g. exposure of pregnant ewes to heat stress will reduce the fetal growth and the degree of reduction is proportional to the length of exposure.

- Further variations between species, strains etc. depend upon genetic set up. In some species, breed differences can be detected even during very early stage, though there is no difference in their egg size.

TYPES OF ORGAN GROWTH

Isometric growth

- When an organ grows at a same rate as that of the general body growth it is known as isometric growth.

Allometric growth

- When an organ grows at a different rate than the general body growth it is known as allometric growth.
- All the body organs follow both isometric and allometric growth during different periods of life. In the prenatal life, CNS reaches its maximum size followed by circulatory system, bones, muscle and finally the adipose tissues. During the postnatal life loins grow first followed by pelvis, thorax, head and finally the legs. This type-if differential growth may be dependant on the functional needs of the body but at different stages of development.

POSTNATAL GROWTH

- It is defined as the correlated increase in the body mass at definite time interval.

Growth curve

- Growth generally begins slowly, which then undergoes a period of rapid increase followed by slow down or stagnant of growth. Plotting the body weight of an animal on the 'y' axis and the age of the animal on the 'x' axis produces growth curve. It is normally sigmoid shaped in all animals and man. The course of growth after birth is almost similar in farm animals. But the juvenile or the prepubertal period is very long in human when compared to that of the animals. In humans,puberty is attained when the body weight reaches 60%, whereas in animals puberty occurs when 30% of the adult weight is reached. There are few exceptions to V curve i.e. organs like gonads and mammary glands are showing cyclic growth.

- The growth curve has two phases:

Accelerating phase

- It is the increasing slope of the curve, in which the growth rate accelerates to the maximum. Here the steep slope of the curve extends from the beginning of growth until l/3rd to ½ of the mature weight is reached. The following two forces acting on the growth rate which determine the shape of the growth curve:
- Growth accelerating force
  - o Growth accelerating force is present in the body cells and is due to hyperplasia, hypertrophy and inclusion of exogenous substances.
- Growth retarding or decelerating force
  - o When growth cannot continue definitely due to lack of space or food supply, the growth rate retards from this point onwards and the force that act upon is called as the growth retarding force which is found in the environment surrounding the cells.
  - o During the initial linear phase of growth the two opposing forces are in balance.

Decelerating phase/Retarding phase

- It is the decreasing slope of the curve. During this period growth rate declines and ultimately ceases. It is the final phase of growth and it occurs when the animal "approaches its mature body weight. There is an in built restraint on further growth, which progressively reduces the proportion of feed intake. There is stabilization of feed intake and reduction in the increase in body weight until intake equals the maintenance requirement. This may be due to the production of hypothalamic somatostatin.

- At the junction of the accelerating and retarding phase, where the growth rate stops to increase and which it begins to decrease it is called as the point of inflection. Since in all species puberty occurs at this point it is also known as point of pubertal inflection. This point indicates the time of maximum velocity' of growth, age of puberty, beginning of increasing specific mortality and point of reference to determine age equivalents of different animals. This point occurs at 14 years in humans, 9 - 12 in cattle and 6 -7 months in sheep.

Negative growth phase

- In the old age the starts degenerating and this phase is referred as negative growth phase.
- Growth can be expressed in many ways
  - Actual weight or growth curve
  - Percentage increment method
  - Weight gained per fixed unit of time
- For practical application of growth studies, the first two are used and the last method is used to study the theory of growth.
- In actual growth curve, the live weight is plotted against age and it has the typical 'sigmoid' shape. It is very similar in shape for all farm and laboratory animals except for man where it is different due to prolonged prepubertal period.
- The actual gain per unit time is always slow at first, the increases to a maximum and slows down gradually again, giving 'bell-shaped' curve.
- Growth can be expressed in percentage also. The increase in live weight as percentage of previous weight of the individual is always great at first, falls rapidly as the weight of the animal increase and the curve is opposite in shape to actual growth curve.
- In early stages of growth in utero, the developing embryo doubles in size over a 24-hour period. However, the doubling rate slows down and the percentage

growth rate falls. The percentage growth is particularly important for comparing the relative growth rates of" different tissues or parts of the body within the same organism. The percentage growth rates differ for each component or tissue of the body and it is the reason for conformational changes occurring during growth.

- Growth curves of individual tissues and organs are also sigmoid in shape; however, different tissues develop at different times and individual tissue growth curves cannot be superimposed. The order of development of different organs is skeleton, muscle and then fat.

FACTORS INFLUENCING POSTNATAL GROWTH

- Various factors influencing the postnatal growth are

Plane of nutrition

- The influence of plane of nutrition is very important because of its relation to economics of milk and meat production. Varying the nutritional status of the animals during various periods of growth can alter the carcass composition of meat animals.
- The knowledge of this helps the farmers to control the carcass quality of meat animals in order to increase the market demands. The effect of plane of nutrition depends on the stage of growth. If a low plane of nutrition is fed during the accelerating phase of growth it induces retardation of growth.
- All vitamins especially Vitamin B complex, A and C are needed for normal growth.

Milk supplied by the dam

- Milk has growth promoting ability in young animals in addition to its known value as a complete food. For this reason mammalian young ones grow at a extremely rapid rate than the birds.
- Among the birds, pigeon chicks grow at a faster rate than the others because of crop milk production in pigeons.

Sex of the animal

- It depends on the genetic makeup and the sex hormones. Generally males grow faster and reach better rates man females of equivalent ages even if both the sexes are provided with same nutrition.

Nervous System

- It controls growth by directly regulating the feed intake via hunger and satiety centers and indirectly by the release of hormones needed for growth.

Litter size

- Single have better birth weight than the twins, twins are better than the quadruplets. This difference increases during the first month after birth due to limited milk supplied by the dam. But once these animals are fed with concentrate rations the twins overtake singles, the quadruplets overtake twins. The twins when reared as singles they grow better.

Environmental Factors

- Climate influences growth by influencing indirectly the availability of fodder and directly the animal itself. Summer in the tropics offer poor quality and quantity of fodder thereby reducing the growth rate. In the temperate zone fodder is scarce in winter therefore decreasing the growth rate.
- Further in animals heat tolerance also play a major role eg., African Short horn cattle when maintained in a hot climate with abundant feed, they failed to grow because they cannot consume feed although it was plenty. Similarly Jersey cattle perform better in the tropics due to small body size and low maintenance requirements and better heat tolerance than the H.F cattle.

Effect of Photoperiodism

- Photoperiodic control of growth is most evident in seasonally breeding animals in which the growth and development are seasonally interrelated. There is seasonal variation in sheep, in feed intake, and growth, both are highest in summer and lowest in winter even when fed with concentrates alone. In castrated male the change is less market than the intact ' male.

- The pineal gland is involved in the Photoperiodic regulation of growth. In sheep pineal gland involved in many events such as secretion of reproductive hormones and prolactin. These, events are mediated by secretion of melatonin during periods of darkness. When photoperiodic effect on growth is positive pinealectomy reduces this effect. Long day lengths compared to short day lengths increases serum prolactin and growth hormone levels and increases the growth rate in sheep and goats.

Effect of immune system

- Diseases retards growth of animals by directly interfering with metabolism and absorption or indirectly by affecting the appetite of the animal. If the animals are immunized it will prevent occurrence of diseases and help in optimum growth of animals.

Growth regulators

- These are substances, which have substantial and direct effect on growth. It includes tissue specific growth factors and certain hormones.

DIRECT GROWTH REGULATORS

Tissue specific growth factors

- These act as cellular growth regulators by affecting the proliferation and development of specific types of cells.
    - Insulin like growth factor
    - Epidermal growth factor (EGF)
    - Nerve Growth Factor (NGF)
    - Erythropoietin (EP)
    - Promine and Retine
    - Chalones

INSULIN LIKE GROWTH FACTOR

- In recent years many efforts have been undertaken to elucidate the complex interactions between mediators of the endocrine system and the immune system. The main effector of growth hormone (GH) is insulin-like growth factor-1 (IGF-1), an endocrine mediator of growth and development under physiological conditions. Besides this important function, IGF-1 also plays a prominent role in the regulation of immunity and in ammation.
- Insulin-like growth factor (IGF-I, IGF-II) action is influenced by until today known eight forms of insulin-like growth factor binding proteins (IGFBPs). They have been obtained not only from some human and animal tissues and body fluids but also from conditioned medium of cell cultures. An important biological property of the IGFBPs is their ability to increase the circulating half-life of the IGFs. They are able to act as potentiators of cell proliferation. As IGFBPs bind to cell surfaces, they may act either to deliver the IGFs to those surfaces for activation of specific receptors or to activate cell responses independently of receptor activation. Phosphorylation, glycosylation and proteolysis of IGFBPs influence their affinity to IGFs. The IGFBPs in the role of inhibitors may block the activity of the IGFs and be used for antimitogenic therapy. In the last time measuring of IGFBPs levels can be used for diagnosis of determination of some endocrine diseases or in differential diagnostics.
- High-affinity, soluble IGFBPs are specific proteins able to form complexes with IGFs in extracellular and interstitial fluids of live organisms. They influence IGFs transport to receptors on cell surfaces and also IGFs effects on cell proliferation. IGFBPs are proteins with different size, they are produced by many different tissues, especially by the liver and they bind to IGF-I, IGF-II, but not to insulin (with the exception of IGFBP-7).

• IGFBPs modulate IGFs effects by endo¬crine, paracrine and autocrine mechanisms of regula¬tion. The origin of this regulation may depend on IGFBPs recognition such as glycosylated binding pro¬tein or posttranslation modification such as phospho¬rylation. IGFBPs modify the IGFs effects by regulation of IGFs transport, IGFs concentration in specific tis¬sues, IGFs interaction with cell surface receptors, potentiation or inhibition of IGFs function.

• Insulin and insulin-like growth factors (IGFs) are well known as key regulators of energy metabolism and growth. There is now considerable evidence that these hormones and the signal transduction networks have important roles in neoplasia. Epidermiological, clinical and laboratory research methods are being used to investigate novel cancer prevention and treatment strategies related to insulin and IGF signalling.

o Pharmacological strategies under study include the use of novel receptor-specific antibodies, receptor kinase inhibitors and AMP-activated protein kinase activators such as metformin. There is evidence that insulin and IGF signalling may also be relevant to dietary and lifestyle factors that influence cancer risk and cancer prognosis. Recent results are encouraging and have justified the expansion of many translational research programmes.

o Insulin-like growth factor 1 (IGF-1) has been shown to rescue the aging-related or inactivity-induced loss of muscle mass through the activation of satellite cells. However, the signalling pathways and the mechanism by which IGF-1 affects satellite cells have not been not completely identified.

o peptide included in the insulin superfamily, as its structure and function are the closest to those of insulin and IGF-I. The last decade investigations revealed the biological properties of IGF-II which distinguish it from related peptides. The primary sequence of the IGF-II structure has peculiar differences from those of insulin but insignificant ones from IGF-I. The tertiary strtyucture of IGF-II is similar to that of the related peptide molecules, but a peculiar receptor-binding domain in the IGF-II molecule provides for its unique capability of interacting with receptors.

EPIDERMAL GROWTH FACTOR (EGF)

- It was first isolated from the salivary gland extracts of mice. It is found in significant amount in the submaxillary gland of male mice. Injection of saliva of male mice into new born mice results in
  - o Precocious opening of eyelids as early as seven days; instead 12-14 days.
  - o Precocious eruption of teeth (incisors) at 6-7 days instead of 10 days.
- EGF acts directly on the epidermis rather than through secondary control mechanisms. It stimulates epidermal cell proliferation and keratirdzation
- EGF was discovered by Cohen and subsequently his group expanded our understanding of EGF and its receptor EGFR.9 EGFR is a 170 kDa membrane glycoprotein which is activated by multiple ligands including EGF, transforming growth factor (TGF)-a, heparin binding (HB)-EGF, amphiregulin, b-cellulin and epiregulin, all of which are synthesised as transmembrane precursors (proligands) that are inserted in the cell surface and cleaved by proteases to release the mature soluble growth factor. The EGFR signalling pathway has been known to be involved in a variety of physiological responses including proliferation, differentiation, motility, and survival.
- EGF (Epidermal growth factor) is found in varying concentrations in milk, saliva, urine, plasma and also in most other body fluids. Cells in various organs, including brain, kidney, salivary gland, and stomach, produce this factor. EGF is a globular protein of 6.4 kDa consisting of 53 amino acids. It contains three intramolecular disulfide bonds essential for biological activity. EGF controls and stimulates the proliferation of epidermal and epithelial cells, including fibroblasts, kidney epithelial cells, human glial cells, ovary granulosa cells, and thyroid cells in

vitro. The proliferation of some cell lines have been shown to be inhibited by EGF. EGF is a strong chemoattractant for fibroblasts and epithelial cells. EGF alone and also in combination with other cytokines is an important factor mediating wound.

ANIMAL ECOLOGY

- Ecology is the branch of biology that deals with the relation of living things to their environment, their habits and their mode of life.
- Ecology is divided into two branches

Autecology/species ecology/self ecology

 It is a study of interaction between a single species with its environment. It is primarily experimental.

Synecology/population ecology/biocenology/biosociology

 It is the study of group or community of organisms and their relationship with each other and to their common environment.

- Environmental physiology deals with the surrounding conditions that affect the structures and organ functions of humans and animals.
- Environment includes physical, chemical and biological elements that surround the animals and is therefore included in the study of animal ecology.
- Bioclimatology deals with the inter relationships between climate, soil, plants and animals .

- Weather
  - o It is a short term day to day fluctuations of the meteorological variables.
- Climate
  - o It is a long term average condition of the meteorological variables, in a given region.
- Macroclimate
  - o It is the general large scale climatic conditions of the open atmosphere in a large area or a country.
- Microclimate
  - o It is the climatic condition directly surrounding the animal.

ADAPTATION

- It is the adjustment of an animal to given environment.
- When the animals are continuously exposed to major environmental changes, they may develop functional and structural changes that results in an increase in their ability to live without stress in a new environment. This is called as adaptation.
- There are different types of adaptation:

o **Genetic adaptation**

 It refers to the heritable animal characteristics that are transformed from one generation to the other, which favour survival of a population in a particular environment. This may involve evolutionary changes over many generations (selection by nature) or acquiring specific genetic properties (selection by man).

o **Physiological adaptation**

 It is the capacity and process of adjustment of the animal to itself, to other living material and to its external physical environment.

o **Biological adaptation**

 It refers to the changes with respect to morphological, anatomical, physiological, biochemical and behavioral characteristics of the animal which promote welfare and survival of the animal in a given environment.

o **Phenotypic adaptation**

 These are the changes that occur during the life time of an individual. These are non heritable and it is the individuals response to the environment with accompanying changes in the genotype.

 Phenotypic adaptation can be physical as in callous formation on the hands and feet or behavioral as in taming of wild animals.

o **Nutritional adaptation**

 It is associated with both genetic and physiological adaptation.

- It occurs as a result of climatic and ecological changes. For instance, in the coastal areas of the tropical regions the soil and water are low in calcium and due to heavy monsoon rains the soil is leached out with a loss of calcium. This is reflected in the pastures with low levels of this mineral.

- The low calcium intake by the animals lead to low serum calcium concentrations, but the tropical animals appear to be tolerant of this and surfer no ill effects.

Acclimatization

- It refers to long-term adaptive physiological adjustments, which results in an increased tolerance when exposed to continuous or repeated climatic stressors (normally produced under field conditions). E.g., if an animal voluntarily migrates from a mountain valley to a high altitude, its lung ventilation rate typically will increase initially to acquire adequate oxygen.

- Within few days or weeks, lung ventilation begins to drop back towards the sea level rates as other physiological mechanism that facilitates gas exchange at high altitude begins to operate. After several days the individual is said to be acclimatized to a new high altitude conditions.

- Characters of well adapted animals:

  - There must be minimum weight loss when exposed to some stressors like nutritional deficiency, high milk production even when animals are transported.

  - It must have high reproductive rate.

  - It must have high resistance to diseases.

  - High longevity and low mortality.

Acclimation

- It refers to the adaptive changes that take place in response to a single climatic variable.(normally produced in a climatic chamber).

NATURAL ADAPTATION TO ENVIRONMENT

- Desert animals have relatively long legs which permit them to travels long distances in search of food, camels have large flat foot which enable them to move over the shifting sand.
- Animals adapted to cold climate have relatively small surface area relative to body mass (European cattle).
- Animals adapted to warm climate have large surface area relative to body mass (Zebu cattle).
- Coat thickness and hair characteristics in mammals and plumage in birds are also influenced by climate.

Natural - Morphological, Anatomical, and Functional adaptations of animals

S.No	Environmental Conditions	Adaptive Mechanism	Species
1.	Solar Radiation	Long limbs and short reflective coat	Camel
2	High Temperature	Increase in surface area by the skin folds, small body, loose coarse wool, long ears, hair shedding in summer	Tropical cattle, sheep and donkeys
3	High Humidity	Decreased hair coat, Dark pigmentation	Buffalo
4	Cold Temperature	Long hair Minimum exposed extremities, increased s/c fat, abundant brown fat, thickest heavy coat	Temperate cattle, sheep, Yak
5	Desert	Thick skin, increased water drinking capacity, conservation of metabolic water, hard	Camel

		tissue and thick skin around the mouth	
6	High Altitude	Increased oxygen carrying capacity in blood through increased concentration of RBC. Ability to transfer oxygen from capillary blood tissues cells at less pO2	llamas, Alpaca

Adaptation of cattle Animals are transported from temperate to tropical zones and from semitropical zones to cold environment.

• Transportation does not change the inherent genetic characteristics of the animal for adaptation to new environment.

• Indian cattle are more heat tolerant than the European cattle

o Indian cattle have long dewlaps and sheaths (naval flap in females) and long ears have excellent heat dissipation mechanism. These animals have smaller body, resulting in larger surface area per unit weight and their skin has little hair whereas,

o European cattle have fat, hairy, tight hides, under dewlaps and small ears.

o In zebu cattle, the hump in high in fat less blood supply and has less sufficient fat than European breeds. Storage of fat makes zebu more heat tolerant.

o Indian cattle have more extensive system for evaporative cooling and allows them to adapt better to hotter climates.

o Indian cattle are more resistant to ticks, flies and mosquitoes.

o Hair colour of Indian cattle is lighter and thus reflects more sunlight than that of European cattle.

o for European cattle it is between 30-60°F, Indian cattle - 50-80°F. Therefore above 60°F European cattle and above 80°F in Indian cattle, thermo regulatory mechanisms become active - Increased in respiration and evaporation.

THEORIES OF MORPHOLOGICAL ADAPTATION

• Some ecological rules explain morphological adaptations in domestic animals. They are summarized by Brody

o **Bergman's rule (1847):** It relates body size to climate.

o Small light animals have large surface area per unit weight and hence lose heat more rapidly than large heavy animals, which have small surface area per unit weight.

o Larger breeds of cattle (Holstein) are better adapted to cooler areas and smaller (Jersey) breeds are better adapted to warmer areas.

o **Allen's rule (1877):** In a given species animals that live in cold areas tend to have shorter extremities than those in warm climate.

o **Wilson's Rule (1854)** relates insulating cover to climate. Breeds in cold climate have a dense, heavy, thick external coat and those from warm climate have short, glossy and thin hair.

o **Gloger's Rule (1833)** relates colour to climate. Skin pigments protect against UV radiation. Animals in cooler of hot, dry climate have light coloured skin. Skin pigmentation darkens with increasing temperature and humidity.

o **Claude Bernard Rule (1876)** relates climatic changes to internal body changes. The vasomotor dilation and contraction regulates rates of blood flow to skin capillaries.

TEMPERATURE REGULATION

• Body functions mainly depend on body temperature.

• Either increase or decrease in temperature will alter the chemical processes occurring in the body.

• This makes a relatively constant temperature necessarily to be maintained for efficient functioning of all the tissues in the body.

• Based on the stability of the body temperature, animals are classified as

o Homeotherms (or) Warm blooded animals

o These animals have the ability to control their body temperature,. These are called as temperature regulations.

o They have a high rate of heat production of 8-10 times greater than poikilotherms of the same body size and at the same body temperature.

E.g. Mammals and birds.

o The body temperature of homeotherms is higher than the ambient temperature. This also means that heat production must be higher in a cold environment.

o Poikilotherms (or) Cold blooded animals

 These are animals whose body temperature varies with the temperature of the environment.

 They lack physiological control of body temperature. These are called as Temperature Conformers. Eg. Reptiles, Amphibia, Fishes and Invertebrates.

• Based on the source of body heat, the animals are classified as:

o Endotherms:

o These animals generate their own heat through metabolic heat production. Eg. Birds, Mammals.

o They can maintain their body temperature above the ambient temperature. They have well isolated fur, feathers or fat which make them to conserve heat against high temperature.

o They have higher resting metabolic rate of about 5 times more than that of ectotherms of same body size and temperature. (Low thermal conductance)

o Ectotherms:

o These animals depend entirely on the environment for their heat.

o They generate low metabolic heat and have high thermal conductance.

o They are poorly insulated and allows minimum loss of metabolic heat to cooler environment.

o They regulate their body temperature by absorbing heat from the surroundings. Eg. Crab.

Body Temperature

- Different parts of the body have different temperature complete uniformity of temperature is possible if no heat exchange occurs between the body and its environment.

- This difference is due to the variation in the metabolic rate, blood flow and the distance from the surface.

- The core (or) interior temperature is higher than that of the temperature of the extremities.

- The temperature of brain, liver, heart and other active musculature may be 1-2°C higher than that of carotid blood, which is 0-2°C, lower.

- Rumen temperature can exceed rectal temperature by as much as 2°C.

- Rectal temperature is an overall good indicator of core temperature.

- Many factors such as age, sex, feed intake, season, twice of the day, exercise, digestion, pregnancy etc. will affect the normal body temperature.

• The fetus, which has its own metabolism, will have the body temperature slightly higher than its mother.

Normal body temperature of different species

Cattle	Sheep	Goat	Horse	Pig	Dog	Cat	Chicken
38.6°C	39.1°C	39.1°C	37.6°C	39.2°C	38.9°C	38.6°C	41.7°C

• Body temperature is elevated during feeding, exercise , estrus, and at the end of pregnancy.

Diurnal variation (24 hr)

• The domestic animals exhibit a diurnal rhythm of body temperature.

• This rhythm largely reflects the period of rest and activity of the animal.

• The animals, which are active during the day, have their minimum temperature in the early morning and maximum temperature in the late afternoon.

• A reverse of this is found in animals, which are active during the night. The diurnal temperature rhythm can be modified by various routine factors of management.

Thermoneutral zone (Zone of thermal comfort)

• It is the temperature zone at which the performance of the animal is maximized. At this zone, the environmental temperature does not affect the metabolic heat production and circulatory adjustment is sufficient to maintain a thermal constant body temperature.

• Above and below this thermoneutral zone, circulatory adjustments are no longer enough for the maintenance of heat balance. In high temperature, they must be supplemented by increase of evaporative heat loss and in cold temperature by increasing the metabolism.

• The comfort zone varies with age, body size, protective covering, and acclimatization, capacity for evaporative cooling, feed intake and activity of the body.

Critical temperature:

It is the lowest ambient temperature at which a mammal or bird can maintain its body temperature at a normal resting metabolic rate.

- **Lower critical temperature:**

- The environmental temperature below which heat production begins to increase in defense against cold is called as lower critical temperature. The normal metabolic rate is inadequate and the body has to produce extra heat when the environment temperature falls.

- In man and tropical animals the Lower Critical temperature is 25-30°C.

HEAT EXCHANGE MECHANISM

- To maintain a constant body temperature, heat produced and received in the body must be equal to the heat lost from the body. The pathways of heat gain or loss are:

o Non evaporative or insensible heat loss via radiation, conduction and convection.

o Evaporative or sensible heat loss as evaporation of water from the skin and respiratory passages.

Radiation

- It is the energy transfer through electromagnetic waves (heat exchanges between two objects that are not touching).

- Radiant energy does not heat the air directly but indirectly by heating solid surfaces like soil, water, trees, clouds and animals.

- Thus radiant energy is changed into thermal energy, which in turn heats the air by conduction and convection.

- Loss or gain of heat- from a body occurs by infrared waves and it depends on temperature.
- All objects radiates energy. Heat rays leave the body and it is heat loss.
- Animals receive infrared thermal radiation from their surrounding.
- Heat loss/gained by the radiation is influenced bysurface area of the animal, temperature of the animal skin, temperature of the air surrounding the animal and emissivity (ability to absorb and emit heat) of the animals skin.

Conduction

- It is the heat dissipation from warmer to colder objects by direct physical contact and it depends on the temperature radiant between the contacting surfaces, area of the contacting surface and thermal conductivity.
- Heat loss can be minimized by insulation of fur and clothing.
- Animals can increase heat dissipation in conduction by resting on the cold floors.

Convection

- Heat is transferred from one molecule to another and is then carried away i.eheat is transferred to air which rises and takes the heat which it cooler air comes into replace warmer air.
- Higher air velocity increases heat loss by convection. Effectiveness of convective heat loss is effected by:
    - Body surface area
    - Velocity of air movement
    - Surface temperature
    - Air temperature

- The air adjacent to the body surface is usually warmer than the surrounding environmental air and replacing the warmer air by the cooler atmosphere air removes heat from the animal by convection. Convection is enhanced by wind. Warm air blowing over the animal provides convective heat gain to the animal.

Evaporation

- Most important mechanism of heat dissipation during severe heat exposure when the temperature and radiant between the body surface and environmental air becomes narrow.

- Evaporation of water from the skin depends on:

  - Temperature and moisture of the skin

  - Skin covering - hair, wool, etc.,

  - Humidity, velocity, and temperature of the surrounding air

  - Respiration rate and volume

  - Water available for evaporation

  - Surface area of the animal

- Thick hair coat may reduce air movement over the skin and entrap layer of moisture over the skin surface and reduces evaporative loss.

- When the environmental temperature is above that of the body, water evaporation in the principal mechanism.

Heat Gain

- Animals gain heat through internal body activites and may also gain heat from external sources through radiation, conduction, and convection.

- Heat gain to the body through metabolism occurs by oxidation of nutrients. Animals require heat / energy for maintaining circulation, respiration, excretion, muscle tension etc, which is called as Specific Dynamic Action (SDA) heat. This maintenance energy is given off as heat.

- In cold condition, animals have to conserve/produce heat. They absorb heat from the surrounding objects if their temperature is higher than their own. Some heat is also gained by ingestion of food.
- Heat production varies among animals per unit weight.
- Zebu cattle produce 20% less heat than European cattle, which makes them to be more heat tolerant and less cold tolerant.
- Males have a higher BMR than females and castrated males.
- Lactating cones produce more heat than non-lactating dairy cones of the same size.

Heat Dissipation / Loss

- To maintain homeothermy animals dissipate excess heat produced by internal sources or received from external sources.
- Heat produced in animals is dissipated by conduction, convection, evaporation, and radiation and through respiration tract and factices and urine.

PHYSIOLOGICAL RESPONSES TO HEAT

Circulatory Adjustments

- Cutaneous vasodilatation causes a rise in skin temperature, this increases heat loss.
- This cutaneous vasomotor reactions in response to thermal changes is mediated mainly by sympathetic vasoconstrictor-nerves.
- Peripheral vasodilatation is brought about by inhibition of sympathetic vasoconstrictor nerves.
- The stimulus for this is the temperature of the blood circulated to the brain. Thermosensitive cells are present in the anterior hypothalamus that will respond to warmth and evoke thermoregulatory mechanism for heat loss. Thermoreceptors present in the skin may also bring about this response.

Evaporative heat loss

- Evaporation of water will cause an effective cooling of the body.
- Three types of evaporation (perspiration) are common
  - o Insensible perspiration- diffusion of water,
  - o Thermal sweating from the sweat glands
  - o Non-thermal or emotional sweat.
- Insensible perspiration
  - o It is continuous, occurs by diffusion of water through the skin and from lungs.
  - o Thermal sweating occurs from the sweat glands.
  - o Humans may perspire 2 liters of moisture/ hour under dry desert non-shaded conditions.
  - o Evaporation of water is an effective way of cooling the body.
  - o The amount of heat loss by evaporation of 1.0 g of water is proximately 580 calories.
  - o At ordinary temperature and humidity, about 25% of the heat produced in resting mammals is lost by evaporation of water from the skin and respiratory passages.
- Sensible heat loss
  - o Sweating and panting increase heat loss.
- Sweating
  - o There are 2 types of sweat glands:
    - Eccrine glands:
    - These are found mostly in humans and responsible for thermal sweating.

- In domestic animals they are limited (found in the foot pads of dogs).

- This gland produces an aqueous secretion

- Apocrine glands:

- They produce a protein containing secretion,

- In the goat and the sheep the apocrine sweat glands are under direct nervous control,

- In many domestic animals, apocrine sweat glands are important for evaporative heat loss.

o Thermoregulatory sweating is brought about in two ways:

- By a rise of hypothalamic temperature

- Reflexly by stimulation of warmth receptors in the skin and other parts of the body outside the CNS.

o In larger animals sweating is important whereas in panting is more important in smaller species like dogs and sheep.

o In case of horses sympathetic nerves control sweating in response to heat with epinephrine as a transmitter substance.

o In dogs sweating is insignificant in heat regulation and polypnea and panting are more important:

Panting and polypnea

- Panting is an effective way of dissipating heat load.

- In many species heat load will evoke polypnea and in some polypneic panting. Panting consists of increase in respiratory frequency with a decrease in tidal volume. It is more effective in dogs. Breathing occurs at a frequency of 200-400/minute with an opened mouth. Panting is accompanied by increased salivation thereby aids in evaporative cooling. Panting is increased dead space ventilation without change in respiratory alveolar ventilation. Panting is stimulated reflexly and centrally.

- In birds sweat glands are absent and increased evaporation occurs not only by panting but also by gular flutter. Gular flutter is the rapid oscillation of the thin floor of the mouth and the upper part of the throat.

Wallowing

- Pigs and porcine species and water buffaloes have a relatively poor evaporative loss mechanism and depend on wallowing for evaporative heat loss.

Saliva spreading

- Spreading of saliva on the fur when they are heat stressed for evaporative heat loss is seen in rodents and macropod marsupials.

PHYSIOLOGICAL RESPONSES TO COLD

- When there is a fall in the environmental temperature, a drop in animal's body temperature is prevented by a reduction in heat loss by physical regulation. When this physical regulation becomes insignificant to maintain the body temperature heat production will be increased as a line of defense by means of chemical regulation.

Reduction in heat loss

- **Behavioral response**

  o A reduction of heat loss is brought by adoption of posture such as curled up position of animals at rest. So that the surface area exposed to cold will be reduced.

- **Increased fur insulation**

  o In case of prolonged cold exposure, the animals will develop increased fur growth and subcutaneous fat as a means of increasing peripheral insulation.

- **Piloerection**

  o It occurs to reduce the insulation value of hair or fur. In this process the hairs become more erect and is brought about by the erector pili muscle of the hair follicle.

- **Circulatory Adjustments**

o When exposed to cold vasoconstriction occurs in the skin and superficial tissues mediated by the vasoconstrictor nerves there by reducing the heat loss in 2 ways:

 Vasoconstriction decreases the peripheral blood flow causing a drop in skin temperature there by reducing the temperature gradient between the skin and the environment.

 It increases the functional insulation of the skin because of reduction in convected heat loss of the perfusing blood.

o An increase in vasoconstrictor tone may be elicited reflexly by stimulation of skin cold receptors or centrally by a lowered hypothalamic temperature. The other important mechanism by which heat is gained is by the arrangement of deep arteries and veins that run close together helping in counter current heat exchange. Hence the cold venous blood is transported centrally adjacent to warm arterial blood coursing peripherally. By continuous heat exchange, the returning venous blood is cooled which minimizes the heat loss to a cold environment.e.g.,Pampiniform plexus to maintain the testicular temperature.

Increase in heat production

• When the reduction in heat loss is not sufficient to maintain a constant body temperature, heat production has to be increased called as lower critical temperature and it varies in different animals. Among the farm animals, cattle and sheep have the lowest critical temperature and are therefore able to withstand cold.

• Increase in heat production is brought about in 2 ways:

o Shivering thermogenesis

o Non shivering thermogenesis

• Shivering thermogenesis

o During sudden exposure to cold, shivering is the major contributor to enhanced heat production (increases the BMR 5-10 times the normal). It may increase the oxygen consumption to 400%. It is an involuntary function of the body.

o It consists of muscle tremor with a frequency of about 10/second. The heat is generated through shivering to withstand cold where in 75 % of energy released for muscle contraction is converted into heat. It is initiated by peripheral and central thermoreceptors.

• Non shivering thermogenesis

o Heat production occurs in the absence of muscular activity. Heat is generated apart from shivering by means of enhanced mobilization of fat from white adipose tissues, increases triglycerides uptake, lipogenesis and lipolysis when the animal is exposed to cold.

o This non-shivering thermogenesis is due to the release of epinephrine and nor epinephnne during cold exposure.

o Epinephrine and nor epinephrine has got calorigenic effect which is potentiated by thyroxine.

o ACTH also plays a role. In birds glucagon enhances/calorigenic effect.

o In neonates, non-shivering thermogenesis is higher than the adult.

o In new born animals of several species and in hibernating animals /brown adipose tissue is an important source of heat. When the animal is exposed to cold, it causes a high increase in metabolism and blood flow.

o During cold adaptation, hypertrophy of brown adipose tissue or fat occurs whereas it decreases in warm adaptation.

Adjustments during prolonged cold exposure

• The physiological adjustments to prolonged cold exposure is divided into 3 categories:

o **Cold acclimation:** The changes occurring during cold exposure for a few weeks when other environmental factor remains unchanged. It involves a shift from shivering to non-shivering thermogenesis occurring during the first 2 or 3 weeks of cold exposure. Increase in non-shivering thermogenesis enables the animals to survive longer than non- acclimated animals in severe cold. In cold acclimated animals carbohydrate and fat metabolism increases, storage of brown fat increases and the calorigenic effect of epinephrine and nor epinephrine is potentiated by thyroxine.

- **Cold acclimatization:** Animals living in cold climate maintain a normal body temperature mainly by adjustments involving improved insulation. There by they have a lower critical temperature than the animals of the same species not acclimatized to cold. Heat production is not elevated in cold acclimatized animals. It involves modifications developing during slow seasonal change from summer to winter. In many arctic animals the metabolism in winter is less than that during summer when measured at a given external temperature.

- **Climatic adaptation:** Genetic adaptations of animals occur as a result of natural selection so that they are best suited for survival in a cold climate. The body temperature of homeotherms does not show any adaptive changes. Arctic mammals maintain their body temperature at a high level by most efficient insulation and do not increase their metabolism until the environmental temperature is very low. The rectal temperature of arctic and tropic mammals will not vary significantly during extreme cold climate. Lower critical temperature for Eskimo dog is -10°C, arctic fox is -30°C, and man and large tropical animals is 25-27°C.

- **Cold habituation:** Animals that are experiencing a mild cold stress for extended period, when suddenly exposed to severe cold, for several hours, they delay their thermogenic reactions to the acute cold. This is cold habituation and it is enables the animals to withstand acute temperature of short duration without increasing their metabolic rate and conserves energy. If the cold stress prolongs for larger duration, then heat production increases to maintain body temperature.

TEMPERATURE PERCEPTION AND REGULATION OF BODY TEMPERATURE

- Temperature perception is mediated by peripheral thermo-receptors and CNS thermodetectors. Their joint action seems to be necessary to obtain the maximal temperature regulation against heat or cold.

Peripheral thermoreceptors

- The sensations of warmth and cold originate from thermo-receptors in the skin and certain mucous membranes. Warmth receptors detect rise in temperature and cold receptors detect drop in temperature.

- Certain areas of the skin are of greater importance than others in the peripheral control of body temperature e.g. local warming of the scrotal skin in the ram elicits polypnea much more readily than any other skin area in this animal.

CNS thermodetectors

- The anterior hypothalamus is sensitive to an increase or decrease in body temperature. There are thermosensitive neurons located in the hypothalamus that detect the - changes in the temperature. These neurons increase their rate of discharge with increase in local temperature from 34 to 41°C.

- When the temperature of blood perfusing the hypothalamus is above normal, the anterior hypothalamus activates physiological and behaviour heat loss mechanisms and inactivates heat gain mechanisms. When the temperature of hypothalamic blood is lower than normal, the anterior hypothalamus initiates heat-gain mechanisms. Spinal cord also contains thermal sensitive areas, which is more important in birds.

Interaction between neural and hormonal thermoregulatory mechanisms

- In addition to neural mechanisms, hormonal mechanisms also participate. Epinephrine, norepinephrine and thyroxine are important in cold exposure. Epinephrine, norepinephrine and thyroxine are of major importance in cold stimulated non-shivering thermogenesis. An increased secretion of hormones occurs in mammals during cold stress. The thermoregulatory centre in the anterior hypothalamus participates in the control of these hormonal cold defense mechanisms.

- When warm blood passes through anterior hypothalamus, it inhibits the activation of the sympathico-adreno-medullary system and the thyroid activation. Cold blood passing through the thermo-regulatory centre on the other-hand causes sympathico-adreno medullary activation and increased secretion of thyroxine. The latter response is mediated by the release of thyrotropic hormone (TSH) from the anterior pituitary. Thus, changes in deep body temperature influence both neural and hormonal thermoregulatory mechanisms by altering the activity of central thermo-detectors in the anterior hypothalamus.

TEMPERATURE REGULATION IN BIRDS

- Birds are homeotherms and maintain constant body temperature.

- Birds are also endotherms and have special mechanism of increasing their body temperature by heat generation within their tissues.

- In birds, even though similar thermoregulatory mechanisms are available as that of mammals, certain distinguishing differences make the bird more adaptive and precisely control thermoregulation.

- Examples

o Plumage of birds is helpful for flight as well as insulation;

o site of deposition of fat differs in birds;

o availability of salt glands as in ducks prevents dehydration and evaporative heat loss;

o absence of sweat glands.

Core Temperature

- Core temperature varies during the day and is dependent on environmental temperature.

- Circadian rhythm of body temperature reveals the extent to which the bird stores heat and the degree to which the thermo-regulatory control mechanisms operate.

- Factors that affect the core temperature are the amount of plumage, size of the bird, physiological activity of the bird and intensity of light; photo period is a major factor that alters the body temperature and ultimately the productivity of the bird.

• Circadian rhythm of the body temperature is reversed by changing the time and degree of illumination and is beneficially used in poultry industry to enhance productivity. Hormones mainly control circadian rhythm of the body temperature of birds.

Heat production v/s heat Loss

• Body temperature increases as the air temperature increases. At low temperatures, shivering causes thermogenesis to maintain core temperature. In young birds, core temperature is not constant even within the thermoneutral zone.

• During exposure to hot environment, there will be increased rate of heat storage, which raises the core temperature. Birds gain heat from environment. This can be seen in desert environment where the temperature of air and sand will exceed the bird's body temperature; due to increased heat storage, there will be reduction in the temperature difference between the body and the environment and heat gain from the environment is diminished.

• Storage of heat within the body is directly related to saving of water in the body, which helps to dissipate the moisture evaporation. Desert birds become more hyperthermic when they are dehydrated. Following dehydration, there is an increase in the body temperature in all birds, which is due to reduced respiratory evaporative cooling. Food deprivation reduces body temperature, which may be due to decreased metabolism.

• Non-shivering thermogenesis is absent in birds since they do not have the browm fat- an important thermogenic tissue.

Heat dissipation

Radiation

• Skin and plumage are the major factors that participate in radiation heat transfer. Colour of plumage and positioning of plumage alters the degree of radiation.

Conduction

- Rate of heat conduction depends on thickness of the layers of tissues. Tissue fat has the lower conductivity but it does not play a major role in heat conduction.in birds because most birds do not have substantial fat layers under the skin.

- Fat is deposited in the abdominal cavity.

- Plumage of birds provides a very effective barrier to heat loss from skin surface to environment.

- Feathers help trapping air and act as windproof covering; coating of the feathers with oily secretion of preen glands makes the plumage resistant to wetting.

- Some of the birds adapted to freezing temperature have a "cold vasodilation ", by accelerating the blood flow to the foot and extremities that are exposed to cold. The cold vasodilatation prevent freezing of extremities by increasing the heat loss from these parts. Winter fattening occurs in small birds exposed to cold climate.

- Thermal conductance of small birds is greater than large birds because of change in the thickness of the skin and fat.

- Surface area in proportion to body weight is the major factor that modifies the amount of heat that is lost.

Convection

- Birds exposed to moving air or bird moving in air loses much of heat. This ' phenomenon is termed as forced convection and it is approximately proportional to the square root of the air velocity.

- Non-evaporative heat loss is a special process of convection and conduction occurring in the upper respiratory tract; it is similar to counter current exchange pattern and it helps in effective cooling of nasal passage.

- Another feature of birds is fluffing of feathers during exposure to cold. This increases insulation provided by feathers and decreases the thermal conductance of the plumage.

• Fowls with poor plumage have accelerated heat production due to scanty insulation. Thermal polypnoea is another feature that increases evaporative heat loss by increasing respiratory minute volume, and it is characteristic of many hyperthermic panting animals and birds.

• The extensive air sac system helps the birds to get more ventilation during panting, to accelerate the evaporative heat loss. This is one mode of stress management, which aids in evaporative respiratory .cooling without much change in blood gases and acid base balance. In few species, thermal polypnoea would result in mild alkalosis.

• Another feature observed in many birds when exposed to heat is the movement of bucco-pharyngeal area to accelerate ventilation that results in evaporative cooling (gular flutter).

BEHAVIOURAL THERMOREGULATION

• Migration of birds from cooler to warmer areas and vice versa is a thermoregulatorybehaviour.

• Hunching - Birds exposed to cold try to reduce the surface area exposed to cold, to reduce heat loss and it is called hunching. They may tuck their head under the wings to cause further reduction in heat loss. They prefer to sit than stand which minimizes heat loss. Sunning behaviour is observed (birds expose themselves to sun to gain heat) during cold.

• Huddling reduces heat loss, most commonly seen in chicks; the chicks huddle with their mother seeking warmth.

• On exposure to hot environment, they avoid the hottest part, reduce their activity and seek shades. They orient their back of the body to sun feet facing the shades, wings kept apart and away from the body to facilitate convective heat loss.

• Domestic fowl splashes water over its comb and wattles, tend to soak its ventral feathers (belly soaking) and try to keep themselves cool in hot environment.

• The behavioural thermoregulatory response in birds is regulated by preoptic region of the brain, anterior hypothalamus and by peripheral receptors. The peripheral and the CNS neuron: regulate the' body temperature by regulating heat production and heat loss in birds." Cold receptors are present in the tongue, beak, bill and feathered skin areas in the back.

THERMOREGULATION DURING FLIGHT

- During flight, there is a tremendous increase in heat production, which increases the core temperature. Thermal conductance increases during flight as well as accelerated counter current mechanism in the brain blood vessels. The respiratory minute volume increases during flying to meet the increased 02 demand and to enhance heat loss.

AIR TEMPERATURE

- The air temperature surrounding an animal's body is important to its comfort and functioning of physiological processes.

- Heat normally passes by conduction from warm skin to the cooler air around it. As the air temperature rises above the comfort zone, the heat loss decreases and when air temperature exceeds skin temperature, heat will flow in reverse direction. This is a serious problem in hot and dry areas. When air temperature is lower than 5 C, heat flow from the animal's body is accelerated leading to discomfort and lowered performance.

- Animal may also be heated or cooled by temperature of objects in the surroundings. Most important is the heat from the ground. In dry soil, by mid afternoon, ground surface temperature may go >40°C and after sunset, the ground soil cools rapidly. Green vegetation or moist soils heat more slowly; speed, duration and source of wind affect air temperature. If an animal is grazing in a field where the temperature of air is 25° C, it will not experience discomfort, but by mid afternoon, if wind comes from passing over dry land whose temperature is 40° C, the animal's heat load will be markedly increased.

- Altitudes also influence air temperature, which decreases by 0.65°C/ 100m elevations.

- Air temperatures are measured as maximum and minimum and mean daily (average of these two) temperatures. If the difference of maximum and minimum temperature is 8°C but if the minimum is above 24° C, the animal is under heat stress for the entire 24-hour period; if the temperature difference is 22°C or more, it indicates lower night temperature, which can allow the animal to restore thermal balance.

ATMOSPHERIC HUMIDITY

- It indicates water vapourcontent .

- Rate of cooling by evaporation from skin and respiratory tract depends upon the humidity of air.

- Low humidity helps in rapid evaporation (sometimes lead to dehydration).

- In high humidity, evaporation is slow and reduces heat loss, thereby endangering the animal's heat balance.

- Heat retention in hot humid climate is more acute than excessive water in hot dry climates.

- High humidity is conducive to diseases, lowers feed quality, and enhances mineral deficiency. In warm humid areas when air temperature is above 21°C and relative humidity above 60%, it becomes difficult for the livestock to loose heat. In dry areas when temperature is above 32°C with high wind velocity and low humidity (< 20%), it is hazardous for animals due to dehydration problem.

- Atmospheric humidity is expressed as relative humidity (RH), which is the ratio between the amount of water vapour present in air and the amount it would hold if saturated at the same temperature. The RH does not indicate the ability of the atmosphere to accept water vapour given out from the skin and the lung of animals. Vapour pressure indicates the concentration of water vapour in the air and it is expressed as the fraction of total barometric pressure contributed by gaseous water vapour; it is a better measure of humidity because it gives a precise estimation of water content of the atmosphere.

- The RH can be measured directly with a hygrothermograph or indirectly as wet bulb or dew point temperature. Vapour pressure can be determined from meteorological tables using air temperature and wet bulb, dew point or RH.

- Dew point is the temperature at which the air could be saturated by the amount of water present in it.

- Daily maximum RH occurs in the early morning hours and minimum in the early afternoon; however the vapour pressure may be constant throughout the day.

RADIANT ENERGY

- Radiation from the sun, sky and surroundings add to the animal's heat load. Providing shades or shelters that cut off the direct solar energy can reduce it.

- An animal in the open field is exposed to (1) direct solar radiation from the sun, part of which is reflected according to colour and proportion of coat and the remainder is absorbed as heat (2) solar radiation reflected from clouds and other particles in sky, part of which is reflected by hair coat (3) solar radiation reflected from the ground and surrounding objects; the first two contributes 50 % of heat load and the third contributes the remainder.

- The level of radiant energy is negatively correlated with humidity but positively correlated with maximum temperature. White surface reflects high proportion of visible radiation but little of long infrared; polished aluminum reflects very little of both and absorbs most of the heat. Longer wavelengths are absorbed through skin.

- The energy of radiation absorbed by the animal's body is changed into heat, raising the temperature of the animal.

- Measurement of the source of radiation and the amount of radiation absorbed or reflected by the animal are complex process. When the sun is overhead in a clear sky radiation is high; the surface area of the animal presented to radiation varies among species. At noon, in man only a little more than the head is exposed. Due to posture, the greatest surface area exposed in man is between 8 A.M and 10 A.M.; in sheep it is from 10 A.M. to 12 noon. The intensity of radiation decreases with angle of the sun; thus man receives less direct radiation during a day than a sheep or cow.

- Measurement: Approximate estimate of the total radiation exchange of an animal exposed to a particular environment is by using Black Globe Thermometer, which is a sphere fitted with a thermometer, thermistor or thermocouple for recording temperature. The black globe temperature is about 6° C above atmospheric temperature and it is used to estimate the rate of heat gain by the animal in a particular environment.

- For 6 to 12 months in a year in N-S 30° C latitudes, the intensity of direct and reflected radiation results in the animal receiving a significant amount of heat for 5 - 10 hours/day. The radiant heat load is the greatest in the afternoon when the ground radiation and air temperature are high. But the duration of stress period from the radiant energy may extend beyond the day light hours.

- The animal's body absorbs all the radiation coming from infrared radiation irrespective of skin colour or hair coat. On the short-wave (visible) radiation, hair and skin surfaces affect reflectivity depending on the colour.

- The type of instrument used for measuring radiation depends up on the kind of radiation to be measured - ultraviolet, visible, and infrared or total radiation. Two groups of instruments can be used (1) those dealing with the intensity of direct solar radiation and some of the reflected radiation (2) those dealing with all the three components - direct, reflected and thermal radiation.

- If there is a high solar radiation, animal absorbs heat from environment. Animal has to spend more energy to loose the extra heat obtained from solar radiation. Consequently, less energy is available for growth and production.

- Harmful ultraviolet radiations are injurious to underlying soft tissues. Melanin pigment stored in skin of tropically adapted animals protects from their ill effects.

AIR MOVEMENT

- The rate of air movement over the skin of an animal affects heat loss; increased airflow enhances heat loss by evaporation when moisture is present on the skin. But with low moisture, heat loss from the animal is limited. At temperature of $< 29°C$, faster air movement enhances heat loss, at temperature of $> 29°C$ the reverse is true i.e. there will be heat gain.

- Air movement aids in heat loss from the skin by conduction when air temperature is lower than skin temperature; when the air temperature is higher than skin temperature, there will be heat gain from the surrounding.

- Airflow is described as directional or turbulent (rotational). In hot dry area, air flows around 8 kmph or less during the day does not result in drying and heating the animal body. However, in hot dry climate, the rate of air movement is high, which requires providing protection.

- Airflow rates of 8 to 20 kmph do not produce serious problems. During dust storms of several days, sheep avoid grazing.

• Measurement: Wind vane is used to find wind direction and anemometer is used to measure the speed of wind.

RAINFALL

• Rainfall influences the livestock indirectly by influencing the food supplies. The amount of rainfall, its duration and condition of the soil influence the amount of water going to the subsoil. The soil moisture available for crop production depends on total annual rainfall, its seasonal distribution, and intensity, condition of the soil, vegetation cover and rate of evapo-transpiration. If particular area receives sufficient amount of rainfall, green fodder production will be optimum which ensures better food supply to the animal for growth and production.

• The seasonal rainfall pattern determines the amount of feed that can be produced, grazing practice to be employed, and requirement for storage and type of feed preservation system to be followed. In heavy rainfall season, water content of the forage is increased, which limits nutrient availability to the animal. Rainfall also has direct effects on livestock; it helps in heat dissipation but interfere with feeding and health. Animals cease to graze during rain. In hot environment, rainwater may be trapped by the hair coat, which will reduce thermal stress. Rainfall increases humidity. Sheep can thrive in hot, dry climate but hot, wet climate limits sheep husbandry.

• Measurement: Rain gauge is used to measure rainfall. Day to day levels may vary within a small area due to movement of clouds, but monthly of annual totals are reliable for determining patterns of rainfall over a wide area.

LIGHT

• The period of light during the day is called photoperiod; it is the time between sunrise to sunset. Photoperiod varies with latitude and season and it is related to the path of sun. Length of photoperiod near the equator varies only by few minutes; by ±2 hours at latitude 30° and by ± 19 hours at latitude 60°.

• The eyes in mammals and eyes and skull in poultry perceive photoperiod. The information is relayed to the hypothalamus and pineal via superior cervical ganglion; the pineal encodes this information by producing more melatonin in dark than in light (circadian rhythm).

Effects of light on production

- Providing supplementary light of 4-8 hours with natural day light to cows increases milk yield by 7-16%; in ewes, birth weight of lambs is increased; in pigs, the litter weight is increased.
- In heifers and lambs, growth rate increases by extending the photoperiod; in growing pigs, feed intake or weight are not affected. In poultry, providing 14L, 10D enhances growth rate up to 12 weeks of age; after 12 weeks, very little effect is produced on growth. Low light intensity or blue light, which is perceived as less bright by birds than red or white is preferable to stimulate growth up to 18 weeks.
- In ewes, timing of puberty is determined by photoperiod and nutrition. With adequate nutrition, GnRH and photoperiod regulates puberty. During short day with longer duration of melatonin GnRH pulse frequency increases with subsequent LH release and ovulation. Long day length with short melatonin duration causes refractoriness and ovaries become inactive.
- Sheep is the most affected animal by changes in photoperiod. Seasons of high temperature and long photoperiod cause anestrous and decreased fertility and sperm production in ram. These effects are related to GnRH and LH production.
- In cattle, photoperiod does not affect reproductive activity. Growth and shedding of hair coat in cattle is influenced by length of photoperiod.
- In long day breeders like horse and birds require more light hours for growth, reproduction and production.
- In short breeders like sheep and goat require less light hours for growth, reproduction and production.

ADAPTATION TO EXTREME CLIMATIC CONDITIONS

Dormancy

- It is a general term for reduced body activities, including reduced metabolic rate. The types of dormancy are:
  - Sleep

- Torpor
- Hibernation & Winter Sleep
- Estivation

Sleep

- It is studied intensively in human beings and other mammals and involves extensive adjustments in brain functions. In mammals slow wave sleep is associated with both the hypothalamic temperature sensitivity and a drop in body temperature as well as changes in respiratory and cardiovascular reflexes.

- Human beings and many other mammals sleep for hours at a time. Many of the big carnivores (lions and tigers) sleep for as long as twenty hours a day especially after a meal.

Torpor

- It is a stage in which animals or birds make their metabolic activities to decline and reduce their body temperature e.g., Humming birds and small birds. They frequently feed to meet their high daytime metabolic activity and go into a stage of torpor during night when they cannot feed. This is an adaptive mechanism to maintain bodily activities to avoid running out of energy stores.

- Before the animal becomes active, its body temperature rises as a result of a burst of metabolic activity especially through shivering or oxidation of brown fat stores or both. Several species of small mammals also undergo torpor but large mammals have too much thermal mass to cool down quickly for short periods of torpor.

Hibernation & winter sleep

- If the period of torpor is prolonged for weeks or even several months in cold climates in a protected environment especially in higher animals it is known as hibernation and winter sleep. Example Bat, Ground squirrel, Dormouse, Woodchuck, Hedgehog, Groundhog (Marmoset) and Opossum are some of the animals that hibernate. During hibernation all the physiological functions continue at a reduced rate - heart rate, respiratory rate and metabolic rate decreases. Body temperature is lowered comparatively to a level compatible with survival for the speciesi.

• The hibernating animals arouse from their dormant stage periodically example for self defense, urination etc., A protective mechanism against profound cooling exist i.e during hibernation arousal occurs if the body temperature declines to the level near freezing or when the environmental temperature falls below -2°C or rises above 30°C.

• The ability of the hibernators to increase their body temperature from reduced level is facilitated by brown fat. Brown fat contributes 80% of the total heat production during the initial phase of awakening. It is found in the inguinal, auxiliary and sub scapular regions and around the deep blood vessels. Brown fat differs from white fat in that they have fat metabolizing enzymes. The cells of brown fat tissue are sympathetically innervated and are rich in mitochondria and cytochrome. They are extensively vascularised. The blood sugar in some hibernators is considerably lower during winter sleep and in all hibernators, the serum Mg 2+ is elevated during hibernation.

Estivation

• It is summer sleep seen in animals e.g., frog, crocodiles and alligators. When the animals are exposed to hot dry summer, they sleep. The physiological difference between estivation and hibernation is the inability of estivators to withstand low body temperature during dormancy. It is characterized by shallow torpor. Sleeping animals differ from estivating animals in that the estivating animals have prolonged periods with no visible respiratory movements, while animals, which are sleeping, have regular respiratory movements without periods of apnea.

• Hibernators become quiescent during winter and aestivators become quiescent during summer. Hibernators are sometimes also aestivators. Hibernation is a method of avoiding the need for considerable quantities of food that are required to maintain summer levels of metabolism during winter. Aestivation avoids the difficulty of thermoregulation with high levels of metabolism during hot summer e.g., Desert rodents aestivate i.e. become dormant during hottest part of summer with a fall in body temperature, decreases metabolism and as a result a sparing of evaporative loss.

FEVER, HYPERTHERMIA AND HYPOTHERMIA

Fever

- Fever may be defined as any condition of positive heat balance not solely due to food, exercise, or environment. Fever is disturbance of the normal equilibrium between thermo genesis and thermolysis.

- Fever occurs in 3 stages:

  - **I - stage:** heat production is increased but heat loss mechanisms fail to eliminate the excess heat, and heat gain and heat loss is equal.

  - **II- (mid) stage:** once fever reaches to a particular height, body temperature is maintained at that high level; heat gain and heat loss are equal.

  - **III- (termination) stage:** all the heat loss mechanisms are activated and they are able to bring the body temperature to normal.

- Disease organisms, chemical pyrogens like dinitrophenols, thyroxine, surgery etc, may cause fever. Bacteria are found to produce endotoxins. These endotoxins (or exogenous pyrogens) induce a febrile response in man and animals. They are removed from the blood and inactivated by the reticulo-endothelial system.

- The endotoxins induce a release of another agent-endopyrogen from the monocytes and tissue macrophages. These endopyrogens act on the thermo-regulatory centre and facilitate cold defense mechanisms and inhibit the heat loss mechanisms. Endopyrogen may also be released under certain non-infectious conditions. The endopyrogen is Interleukin-I (IL-I). The IL-I causes the release of prostaglandins in the hypothalamus. The PGs cause release of IL-II from the thermtregulatory center, which activates more T- lymphocytes into circulation to enchance, the defense capacity of the body by producing interferon.

- The sensitivity of the hypothalamic temperature sensing neurons to these pyrogenic molecules leads to an elevation in the set point to a higher temperature than the normal. The result is thus body temperature1 rises several degrees and the animal experiences fever.

- During the development of fever, the heat balance is positive due to increased heat production. Later, when the body temperature reaches a certain height, the balance between heat loss and heat production is restored, and the temperature is again precisely regulated at the new high level. Under these conditions, there is still an increased heat production, but this may be only secondary to the elevated temperature, since the velocity of the biochemical reactions follows von'tHoffs Law and increases 2 to 3 times for a temperature rise of 10°C. A rise of 1°C in body temperature should therefore, cause an increase of 10 to 20% in the basal metabolism. Humans can tolerate a temperature limit of about 107 to 110°F. The elevated metabolic rate during the steady state of fever may be more the result than the cause of high temperature. With termination fever, various heat loss mechanisms are activated and heat balance is restored to its normal level.

- Fever is beneficial in many diseases. The rise in body temperature is to confer protection to the animal against bacterial infection. The protection is provided in 2 forms:

o The antiviral and antitumor agent interferon is more effective at higher temperature.

o Elevated temperature also diminishes the growth of the microbes.

Hyperthermia

- It is characteristic of heat stroke and develops when the heat production exceeds the evaporative capacity of the environment, or when the evaporative mechanisms become impaired because of loss of body fluid and reduced blood volume.

- The core body temperature increases and there is a decrease in heat loss and increase in heat gain but the set point of the body thermostat is not altered. Here antipyretics are ineffective and a reversal of body temperature can be achieved only by whole body cooling.

- Non-febrile hyperthermia may also develop in response to drugs that impair the heat dissipation mechanisms and drastically increase the metabolic rate. E.g., genetically determined malignant hyperthermia seen in swines and humans.

- The malignant hyperthermia can be triggered by inhalation anaesthetics and muscle relaxants that cause an abnormal increase of myoplasmic calcium concentration followed by a drastic rise in muscle metabolism and heat production. Once developed malignant hyperthermia is lethal unless intense body cooling is initiated.

Hypothermia

- Hypothermia is a reduction of deep body temperature below normal in non-hibernating animals. It usually develops because of exhaustion of the metabolic cold defense mechanisms.

- Shivering may persist for a long time, causing depletion of skeletal muscle and liver glycogen reserves and also a fall in the glycogen content of cardiac muscle. There is a gradual slowing of heart and haernoconcentration occurs as a result of shift of fluid from the blood to the tissues.

- The lethal low level of body temperature varies among individuals and species. In humans and in dogs, cardiac arrest followed by respiratory depression and death may occur at a rectal temperature of 25°C.

Cold Stress

- Environmental temperature has a direct effect on the animal's energy expenditure and voluntary food intake and hence affects the production performance of animals. The environmental temperature range in which the heat loss from the animal is minimal is known as the thermo neutral zone; the lower limit of this range is called lower critical temperature (LCT). Below LCT the animal has to increase heat production to maintain heat production to maintain homeothermy leading to reduction in conversion efficiency of feed to animal products .

- The newborn are more susceptible to cold. In heavier animals, cold is not much of a problem as they are fed ad libitum. 2 to 3 days following birth is the most critical period for the survival of new born animals.

Effect of cold on production

- Growth

o Cold exposed animals increase feed intake to meet the increased energy expenditure. In pigs, a decrease in temperature from LCT (20-25°C) by 1°C is associated with 1.5% increase in feed intake; growth rate remains almost constant between 8 and 20°C. In birds also, within a temperature range of 7-22°C, growth of cattle is less obvious.

- Production

o Milk production and composition is constant over a temperature range of 0 to 21°C. However, milk production may be reduced due to reduced availability of feed during cold season. In laying hens, at temperatures between 10 and 28°C, the egg weight is increased with improved shell quality; egg production is not affected; however, feed required per egg is higher.

Meat quality

- Prolonged exposure to cold in pigs under restricted feeding conditions results in leaner carcass; with ad libitum feeding, no effect is observed. In broilers, ad libitum feeding produces leaner carcass.

Heat stress

- Heat is the major constraint on the animal productivity in tropics. Growth and production are impaired during heat stress.

- As the ambient temperature increases, heat loss in animals is enhanced through respiration, evaporation of sweat, and by panting. When these mechanisms are not able to maintain homeothermy, the animal reduces heat production, feed consumption and secretion of thermogenic hormones are decreased to lower* the basal metabolism and these effects lead to decline in productivity. If all these mechanisms fail to balance the excessive heat load, the body temperature rises and the animal enters into an acute phase of heat stress. If the exposure to heat is prolonged further, a rapid acclimation takes place and the animal returns to chronic phase of heat stress. Productivity in this phase will be higher than the acute phase but lower than the normal productivity.

Effect of heat on production

• Appetite

o During heat exposure, feed consumption is depressed. The peripheral warmth receptors transmit impulses to the hypothalamic appetite centre to decrease the feed consumption; this reduces heat load. Hypothalamic releasing factors are suppressed with decrease in pituitary hormones; insulin and thyroxine levels also decrease. Metabolic pathways slow down; protein synthesis reduces negative nitrogen balance.

• **Animal production**

o Growth

 Growth performance - growth rate and daily weight gain are impaired at elevated temperature; these are caused by decreased feed intake, decreased anabolic activity (due to decreased voluntary feed intake of nutrients) and increase in catabolism mainly occurring in fat depots. In Brahman cattle, there may be increase in body weight with raising environmental temperature.

• **Milk production**

o Milk Yield in cows is unaffected within a temperature range of 0 to 21° C. Milk production is impaired in cows in hot climate. A rise in temperature by 1.6°C above normal (21°C), decreases milk yields by 4.5%. The reduction in milk yield is greater in high producing than in low producing cows. Total solids, fat protein, ash and lactose are lowered during hyperthermia in high producing animals maintained at 38 C.

o The decrease in yield and constituents of milk during exposure to high environmental temperature may be due to decline in protein, carbohydrate, lipid, mineral and vitamin metabolism leading to negative nitrogen balance. Many hormones like insulin, thyroxin and cortisol also decline and may decreases milk yield.

- **Reproduction**

o In males, high environmental temperature exerts a negative effect on sexual libido, despite the thermoregulatory mechanism of testes.

o Semen fertility and spermatogenesis are reduced, and semen volume is also reduced. These effects reduce male fertility.

o The detrimental effects of temperature on reproductive performance of cow are caused by the external temperature acting through thermoreceptors, photoreceptors, hypothalamus, CNS, endocrine glands and gonads.

o During heat stress, less gonadotropin production leads reproductive failure.

o Reduced thyroid activity also affects the reproduction.

o Deficiency in minerals - P, Cu, Co, I, Zn and vitamin A in heat stressed cows also affects reproduction.

Egg production in birds

- Egg production in birds is not reduced. Exposure to temperature of 38°C decreases both the egg weight and shell quality.
- Fertility and hatchability of the eggs are decreased by high temperature.
- Blastoderm viability is optimum between 10 and 12°C for weeks. At 27°C, hatchability of eggs is decreased.

ADAPTATION TO HIGH ALTITUDE

- High altitude refers to a height of 7500ft or more above mean sea level. Animals living at this altitude suffer from a condition known as mountain sickness. The symptoms seen are distress and generalized fatigue, disturbances in the circulatory, respiratory and reproductive systems and acid base balance disturbances.

Circulatory disturbances

- Increase in blood volume, erythrocyte count (polycythemia)
- Increased heart rate and decrease in haemoglobin -O2 saturation (73%), increased viscosity of the blood- heart has to pump very hard, decreased cardiac output.

Respiratory disturbances

- Increased rate and depth of respiration.
- In extreme altitudes cheyne-stokes breathing is noticed.
- Acid-base disturbances
- Decreased CO_2 level in blood with increase in pH.
- Reproductive disturbances
- Generally in females fertility is not affected.
- Sheep are less susceptible to high altitude than cattle.
- Horses are more susceptible.
- Mules are best adapted to high altitude
- In rabbits and rats male reproduction is affected i.e., testicles become atrophied and germinal epithelium is replaced by connective tissue and spermatogenesis is inhibited. This process can be reversed if these animals are brought back.

Species specific symptoms at high altitude

- Dogs: more affected with mountain sickness, symptoms include sleepiness, vomiting, laboured breathing, muscle weakness and unable to stand. These symptoms are reversed after acclimatization at high altitude.
- Cattle: Brisket disease (Right heart failure)

Adaptation at lower altitude

- The physiological changes at lower altitude occur in under water diving, in mines and in tunnels. There is high pressure in lower altitude and is called as hyperbarism.

- **Physiological effects of hyperbarism**

  - Building up of CO_2, the levels may go up to 3% and in extreme cases may go up to 10%.

  - This high level acts directly on the brain and causes narcosis leading to unconsciousness.

  - O_2 supply to tissues is reduced due to low atmospheric O_2 content.

  - High pressure on the body especially on the thorax.

  - More of N_2 gets dissolved in the 'blood, which acts at brain level leading to nitrogen narcosis. Initially there will be convulsions with seizures finally causing unconsciousness.

Decompression sickness or dysbarism

- This condition is seen when animals are taken from lower altitude to a higher altitude.

- Dysbarism is also known as Bends, Caisson's disease, Divers paralysis. This is mainly caused by N_2.

- When the animals ascend to high altitude, N_2 escapes from the dissolved state in the blood by forming bubbles- small N_2 bubbles cause pain and nerve block where as large bubbles cause air embolism, pulmonary edema and brain damage.

- Bends is a condition of joint pain usually in the legs, arm and neck region.