Energetics and Metabolic Rate

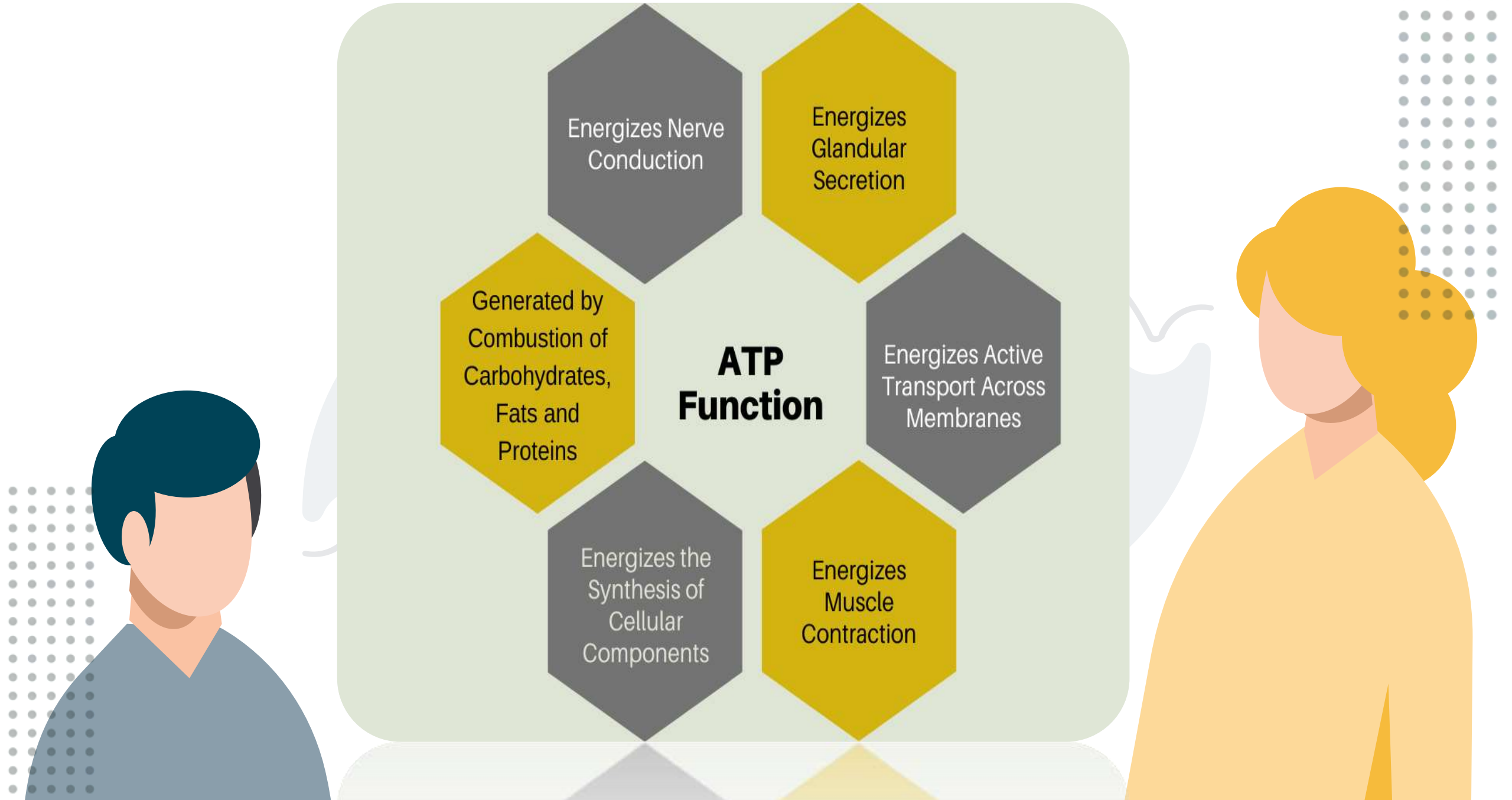
What is the Meaning of Energetics?

- A branch of mechanics that deals primarily with **energy** and its transformations.
- The total **energy** relations and transformations of a physical, chemical, or biological system.

Adenosine Triphosphate Function as an“Energy Currency” in Metabolism

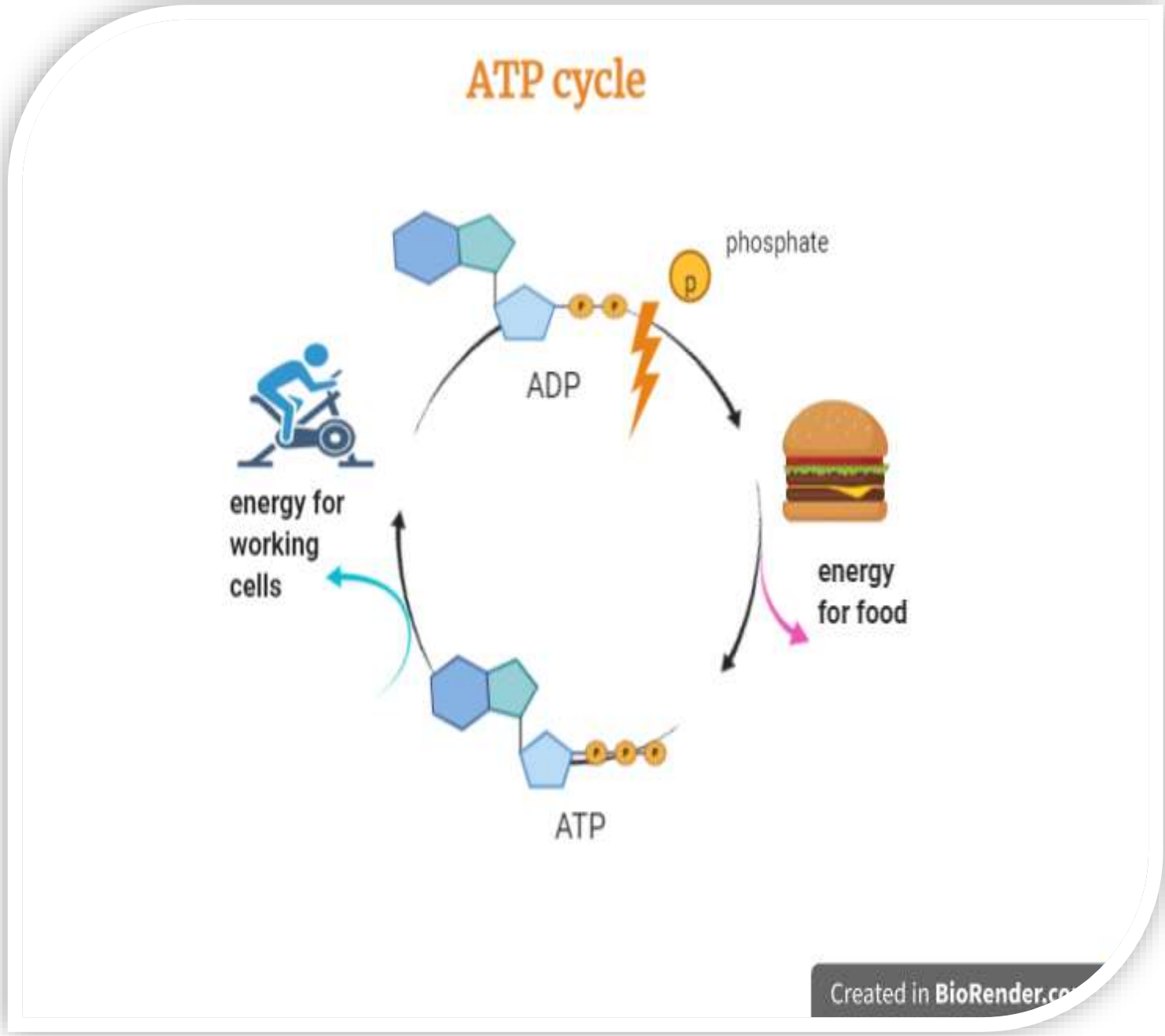
Why is the ATP called an energy currency?

- It can be used as an energy source for almost all cellular functions.
- Transfer of energy from foodstuffs to most functional systems of the cells.
- ATP is highly valuable as an energy currency because of the large quantity of free energy.


Energizes Nerve Conduction
Energizes Glandular Secretion
Generated by Combustion of Carbohydrates, Fats and Proteins
ATP Function
Energizes Active Transport Across Membranes
Energizes the Synthesis of Cellular Components
Energizes Muscle Contraction

The Source of ATP

Carbohydrates, fats, and proteins can all be used by cells to synthesize large quantities of adenosine triphosphate(ATP)


ATP cycle
phosphate
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energy for
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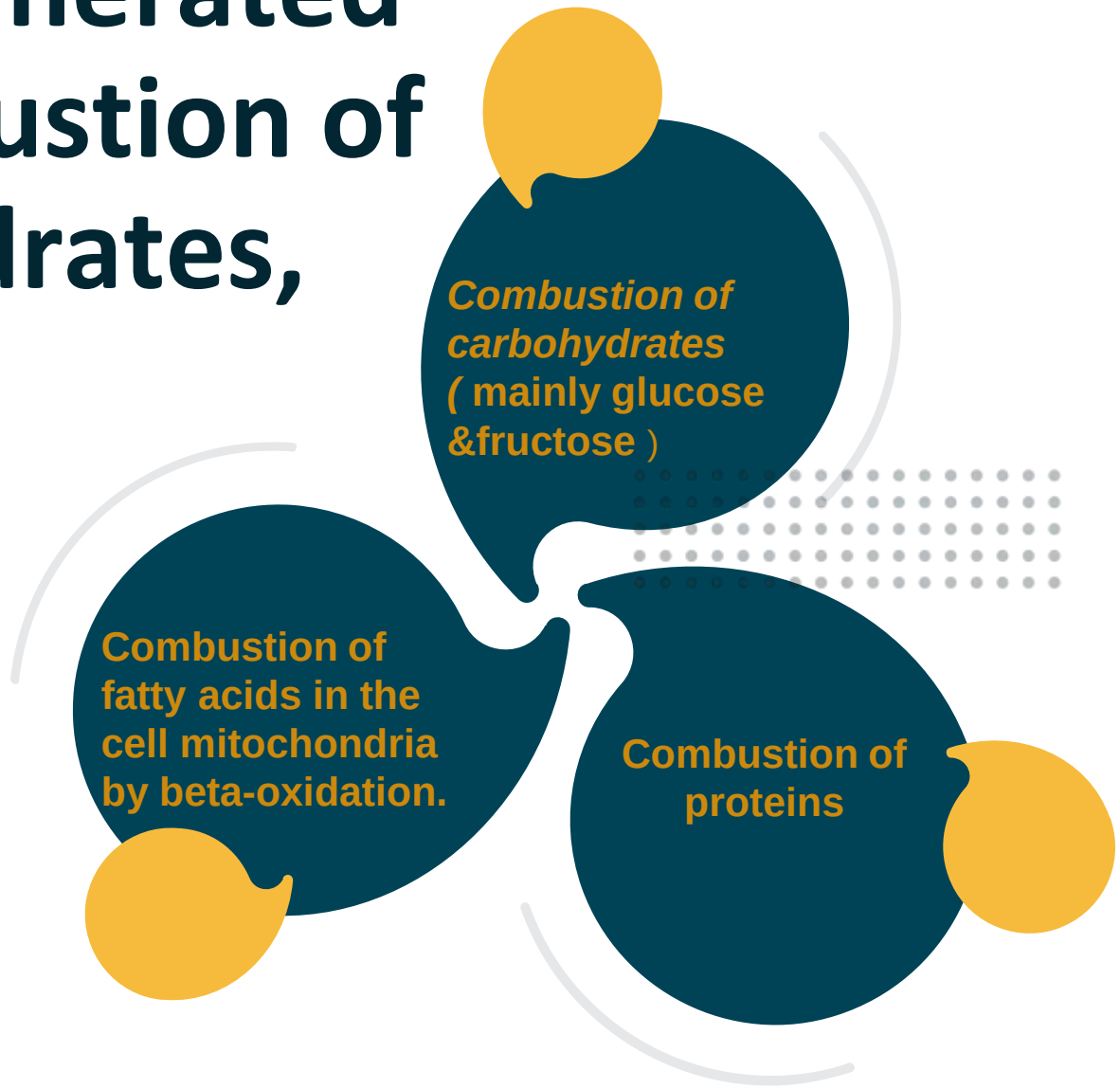
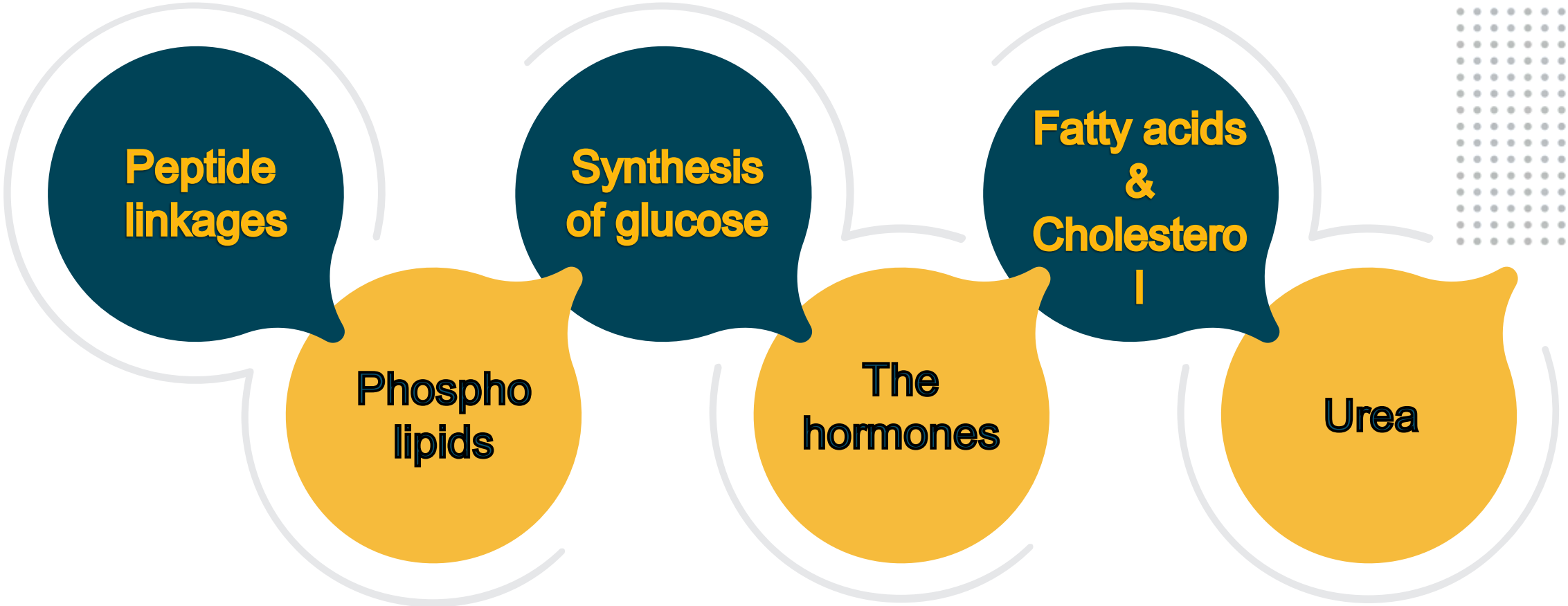
ATP Is Generated by Combustion of Carbohydrates, Fats, and Proteins



ATP Energizes the Synthesis of Cellular Components

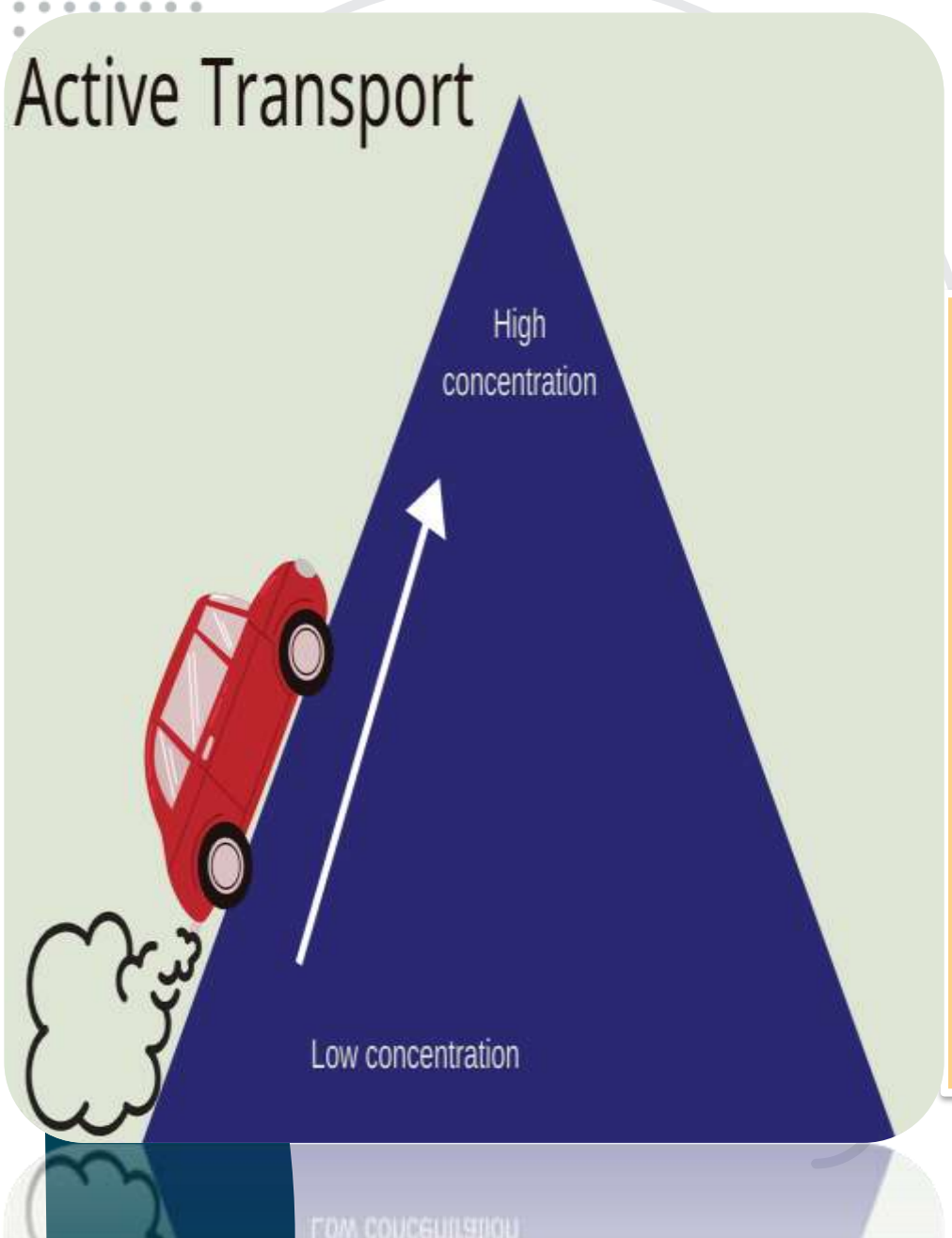


ATP Energizes Muscle Contraction

Muscle contraction will not occur without energy from ATP.

Myosin, one of the important contractile proteins of the muscle fiber, acts as an enzyme to cause breakdown of ATP into adenosine diphosphate (ADP), thus releasing the energy required to cause contraction.

ATP Energizes Active Transport Across Membranes



Active transport of electrolytes and various nutrients across cell membranes and from the renal tubules and gastrointestinal tract into the blood.

ATP Energizes Glandular Secretion

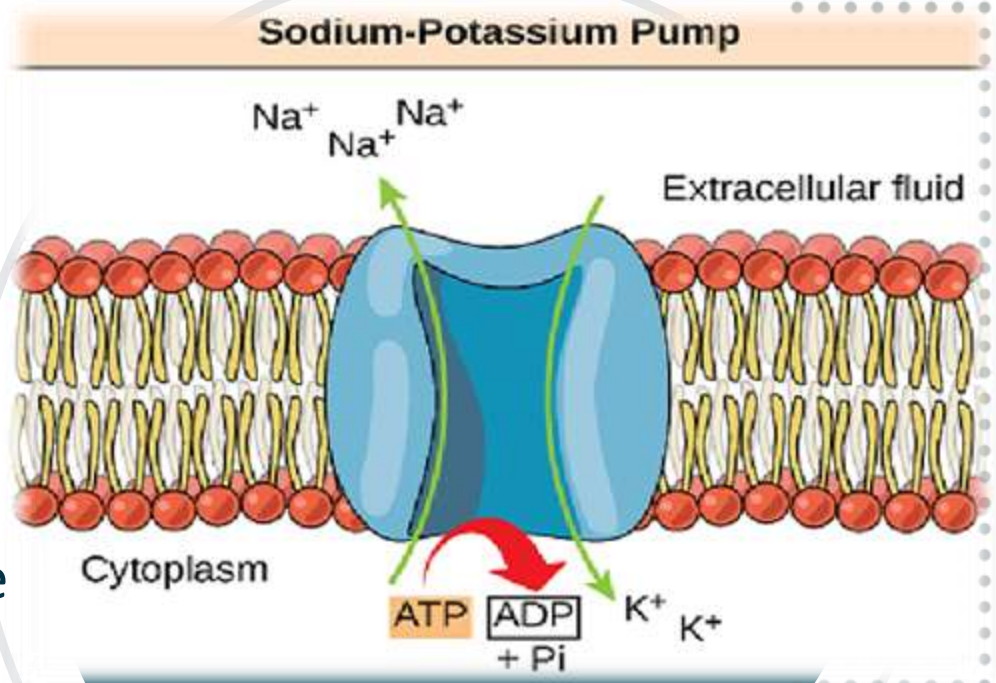
To the absorption of substances against concentration gradients..

Why?

- Energy is required to concentrate substances as they are secreted by the glandular cells.
- Energy is required to synthesize the organic compounds to be secreted.

ATP Energizes Nerve Conduction

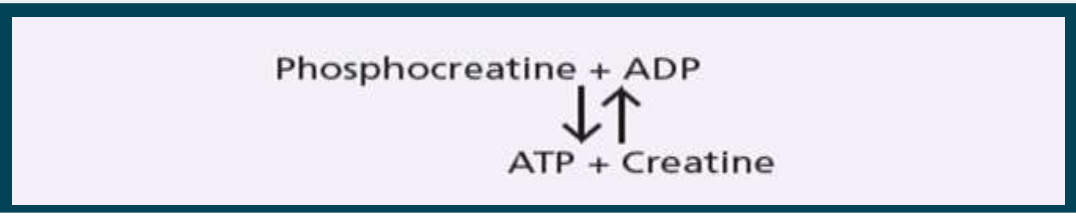
- The energy used during propagation of a nerve impulse is derived from the potential energy stored in the form of concentration differences of ions across the neuronal cell membranes.
- That is, a high concentration of potassium inside the neuron and a low concentration outside the neuron constitute a type of energy storage.
- The energy needed to pass each action potential along the fiber membrane is derived from this energy storage, with small amounts of potassium transferring out of the cell and sodium into the cell during each of the action potentials.



Phosphocreatine Functions as an Accessory Storage Depot for Energy and as an “ATP Buffer”

- ATP is a coupling agent for energy transfer but is not the most abundant store of high-energy phosphate bonds in the cells.
- Phosphocreatine also contains high-energy phosphate bonds, three to eight times more abundant than ATP.

- Phosphocreatine cannot act as a direct coupling agent for energy transfer between the foods and the functional cellular systems, but it can transfer energy interchangeably with ATP.
- When extra amounts of ATP are available in the cell, much of it is used to synthesize phosphocreatine, thus building up this storehouse of energy. Then, when the ATP begins to be used up, the energy in the phosphocreatine is transferred rapidly back to ATP and then to the functional systems of the cells.

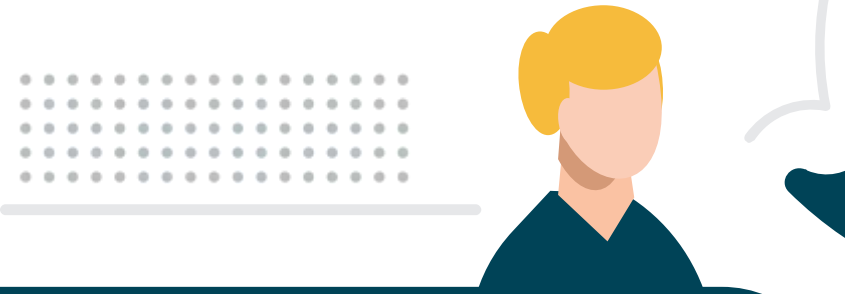


ANAEROBIC VERSUS AEROBIC ENERGY

AEROBIC ENERGY	ANAEROBIC ENERGY
foods	foods
with oxygen	without oxygen
carbohydrates, fats, and proteins	carbohydrates
Complete oxidation	glycolytic breakdown

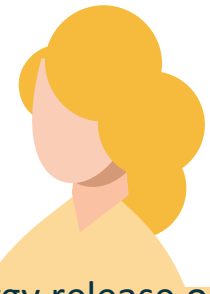
Anaerobic Versus Aerobic Energy

- ***Anaerobic energy* means** : energy that can be derived from foods without the simultaneous utilization of oxygen.



- ***Aerobic energy :*** means energy that can be derived from foods only by oxidative metabolism.

Carbohydrates, fats, and proteins can all be oxidized to cause synthesis of ATP. However, *carbohydrates are the only significant foods that can be used to provide energy without the utilization of oxygen.*



- This energy release occurs during glycolytic breakdown of glucose or glycogen to pyruvic acid. For each mole of glucose that is split into pyruvic acid. *the best source of energy under anaerobic conditions is the stored glycogen of the cells*.

Anaerobic Energy Utilization During Hypoxia

- When a person stops breathing, a small amount of oxygen is already stored in the lungs and an additional amount is stored in the hemoglobin of the blood. This oxygen is sufficient to keep the metabolic processes functioning for only about 2 minutes.
- Continued life beyond this time requires an additional source of energy. It from glycolysis— glycogen of the cells splitting into pyruvic acid, then becoming lactic acid, which diffuses out of the cells.

Anaerobic Energy Utilization During Strenuous Bursts of Activity Is Derived Mainly From Glycolysis

- Skeletal muscles can perform extreme feats of strength for a few seconds but are much less capable during prolonged activity.
- The extra energy comes from anaerobic sources:

(1) ATP already present in the muscle cells.

(2) Phosphocreatine in the cells.

(3) Anaerobic energy released by glycolytic breakdown of glycogen to lactic acid.

Extra Consumption of Oxygen Repays the Oxygen Debt After Completion of Strenuous Exercise.

After a period of strenuous exercise, a person continues to breathe hard and to consume large amounts of oxygen for at least a few minutes and sometimes for as long as 1 hour thereafter.

This additional oxygen is used to

(1) Reconvert the lactic acid that has accumulated during exercise back into glucose

(2) Reconvert adenosine monophosphate and ADP to ATP

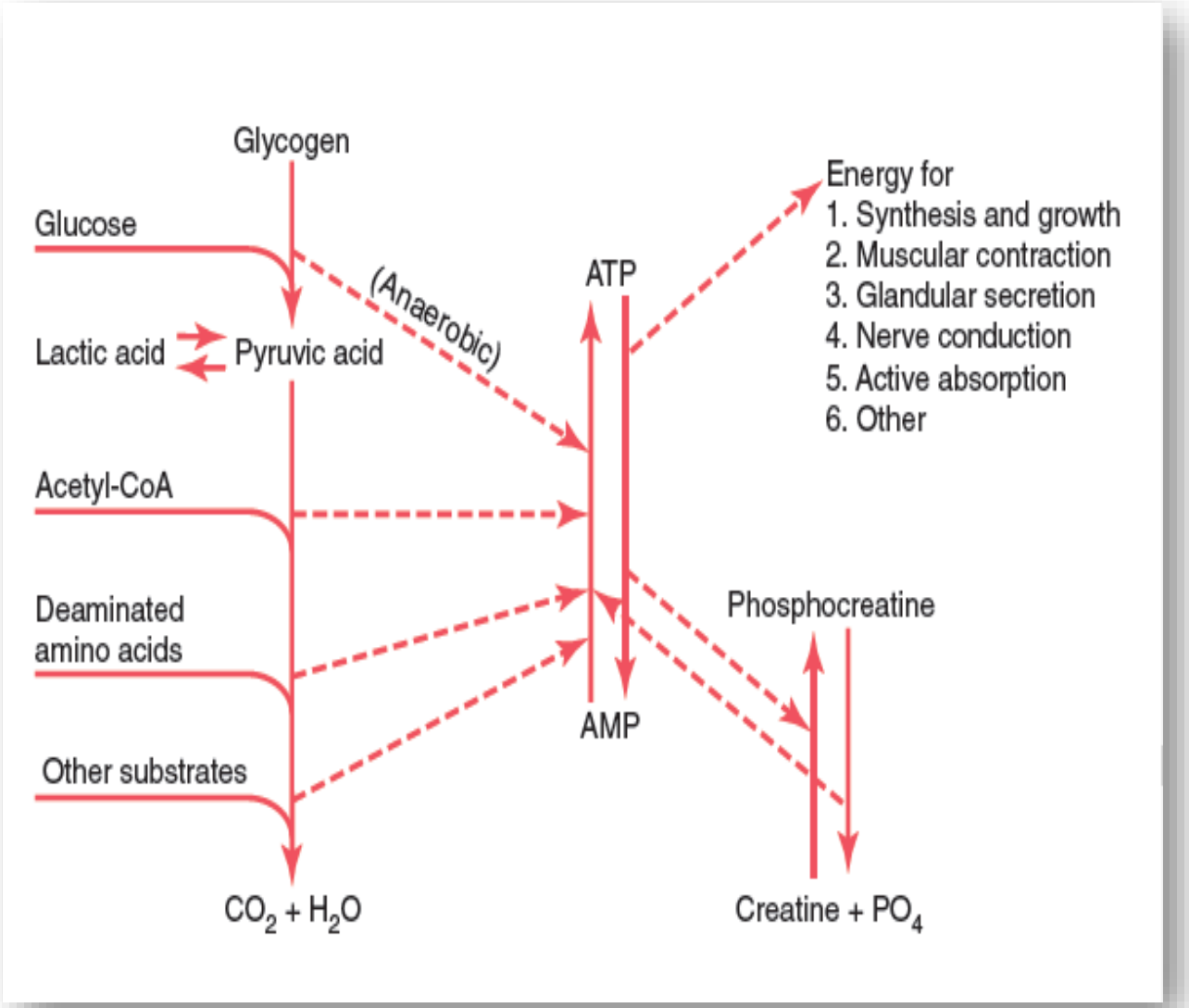
(3) Reconvert creatine and phosphate to phosphocreatine

(4) Re-establish normal concentrations of oxygen bound with hemoglobin and myoglobin

(5) Raise the concentration of oxygen in the lungs to its normal level.

This extra consumption of oxygen after exercise is called *repaying the oxygen debt*.

Summary of Energy Utilization by the Cells



Control of Energy Release in the Cell

Rate Control of Enzyme-Catalyzed Reactions:

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the concentration of
substrate that binds

Role of Enzyme Concentration in Regulation of Metabolic Reactions:

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Regulation of Metabolic

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ADP, increas
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then autom
reactions for the metabolic release of energy from food.

a
complex series of chemical reactions is determined mainly by the rate of reaction of the slowest step in the series, which is called the ***rate-limiting step*** in the entire series.

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Control of Energy Release in the Cell

Rate Control of Enzyme-Catalyzed Reactions:

the rate of the overall chemical reaction is determined by both the concentration of the enzyme and the concentration of the substrate that binds with the enzyme.

Role of Enzyme Concentration in Regulation of Metabolic Reactions:

when the substrate concentration is high, the rate of a chemical reaction is determined almost entirely by the concentration of the enzyme. the rate of the reaction increases proportionately.

Role of Substrate Concentration in Regulation of Metabolic Reactions :

When the substrate concentration becomes low enough that only a small portion of the enzyme is required in the reaction, the rate of the reaction becomes directly proportional to the substrate concentration, as well as the enzyme concentration

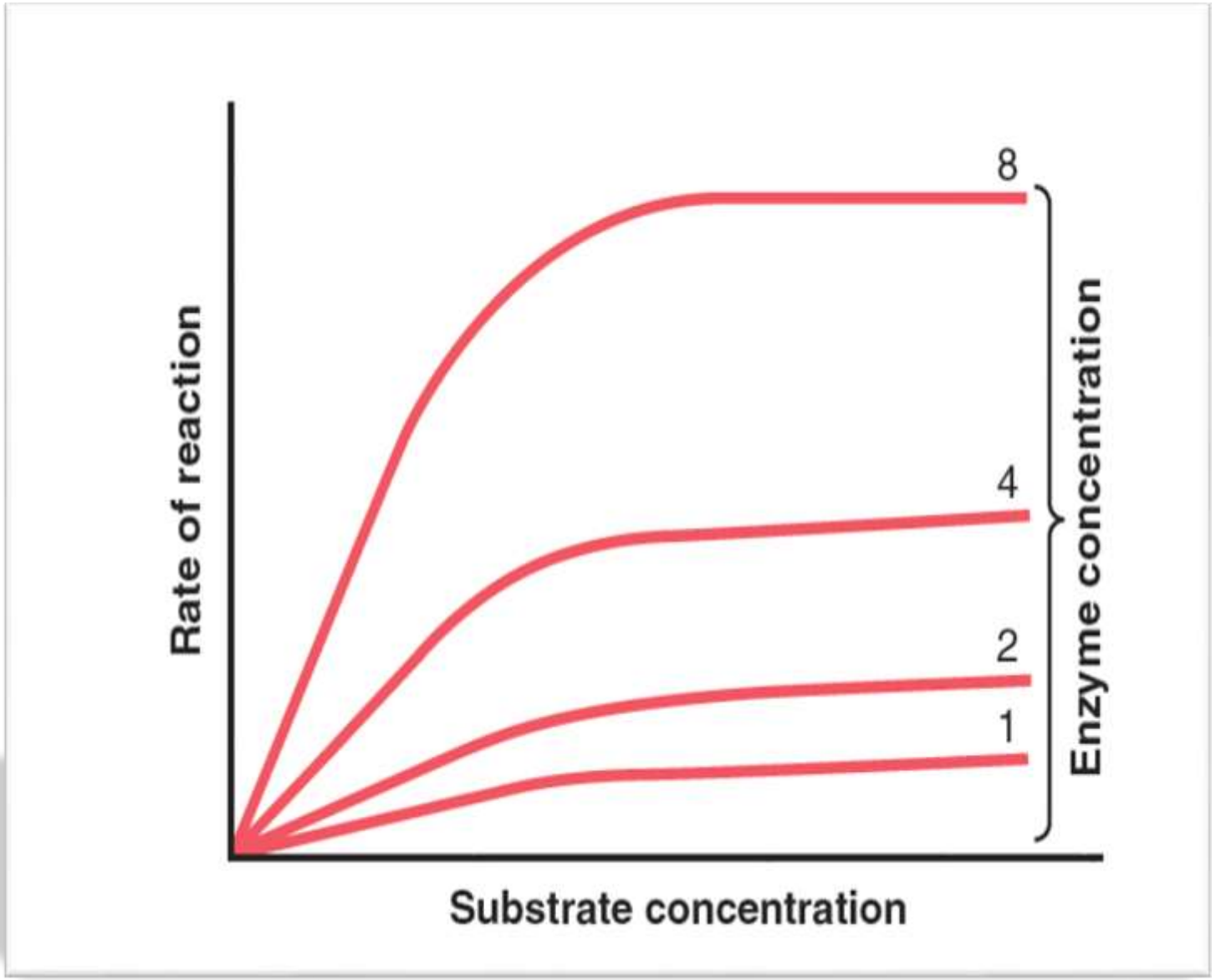
Control of Energy Release in the Cell

Rate Limitation in a Series of Reactions:

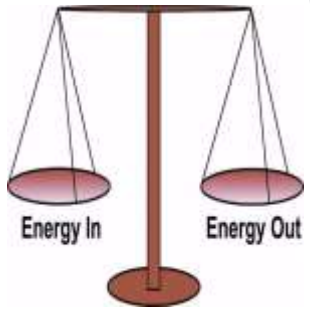
the overall rate of a complex series of chemical reactions is determined mainly by the rate of reaction of the slowest step in the series, which is called the *rate-limiting step* in the entire series.

ADP Concentration as a Rate-Controlling Factor in Energy Release:

ADP is a major rate-limiting factor for almost all energy metabolism of the body. When the cells become active, ATP is converted into ADP, increasing the concentration of ADP in direct proportion to the degree of activity of the cell. This ADP then automatically increases the rates of all the reactions for the metabolic release of energy from food.


Rate of reaction
8
4
2
1
Enzyme concentration
Substrate concentration

Metabolic Rate



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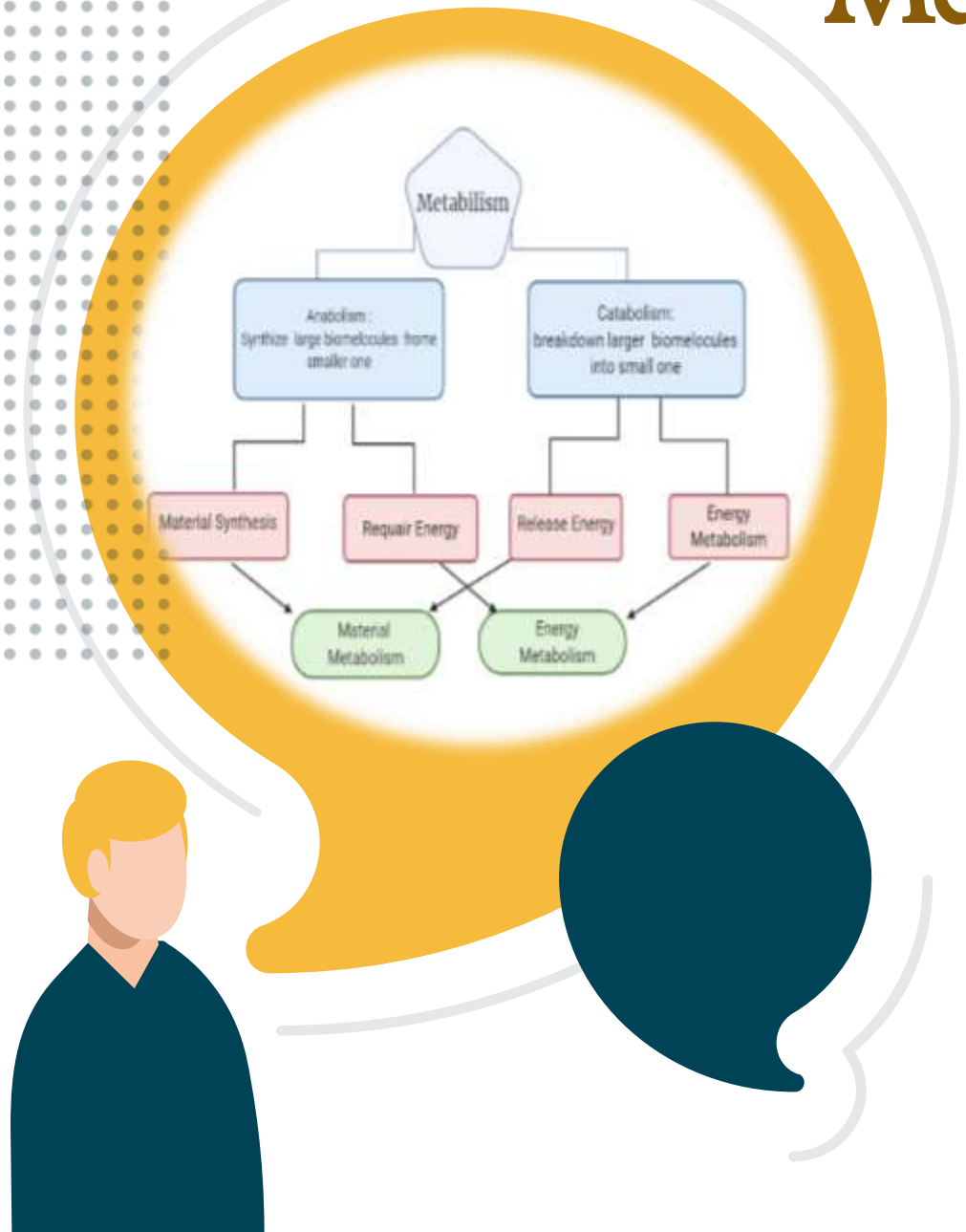
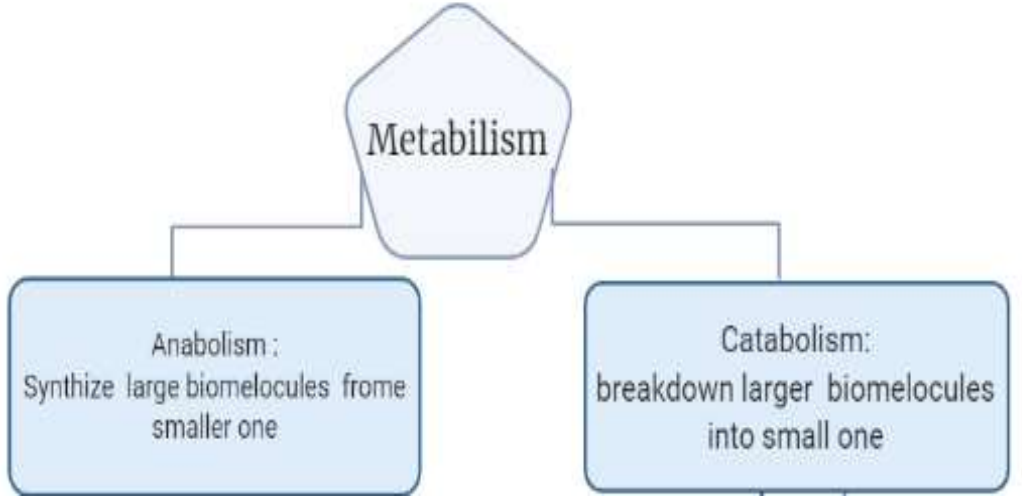
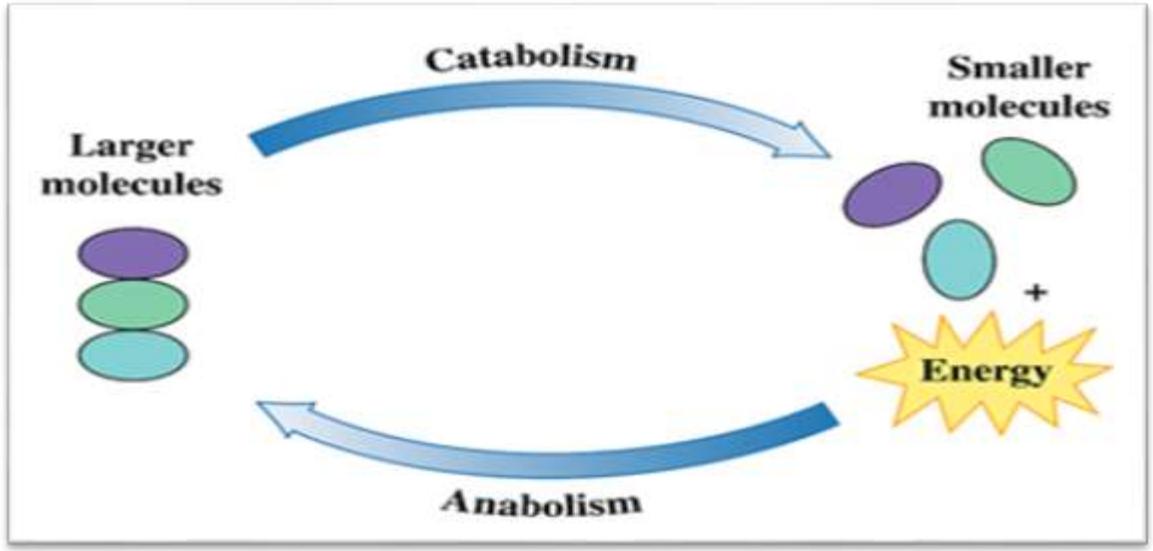
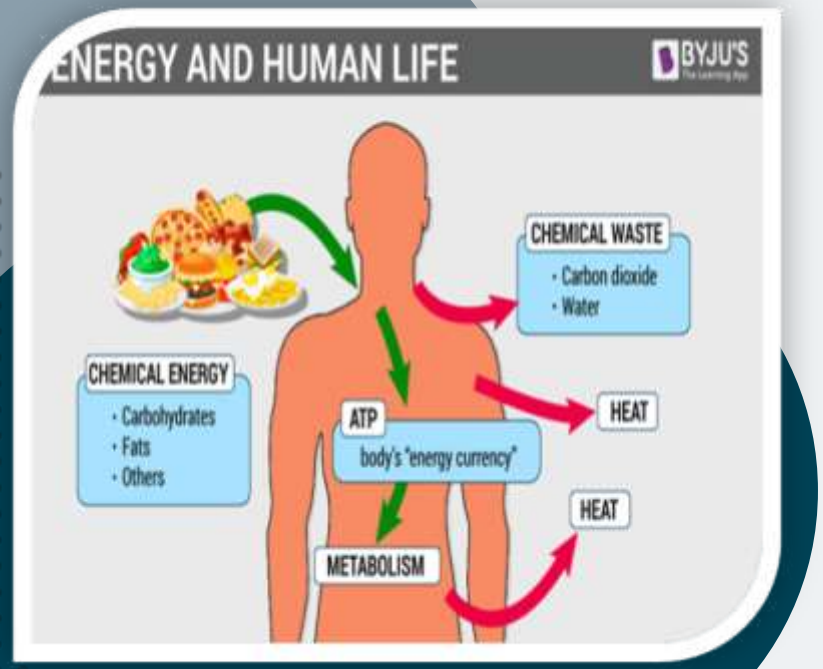
Metabolic Rate







Definition



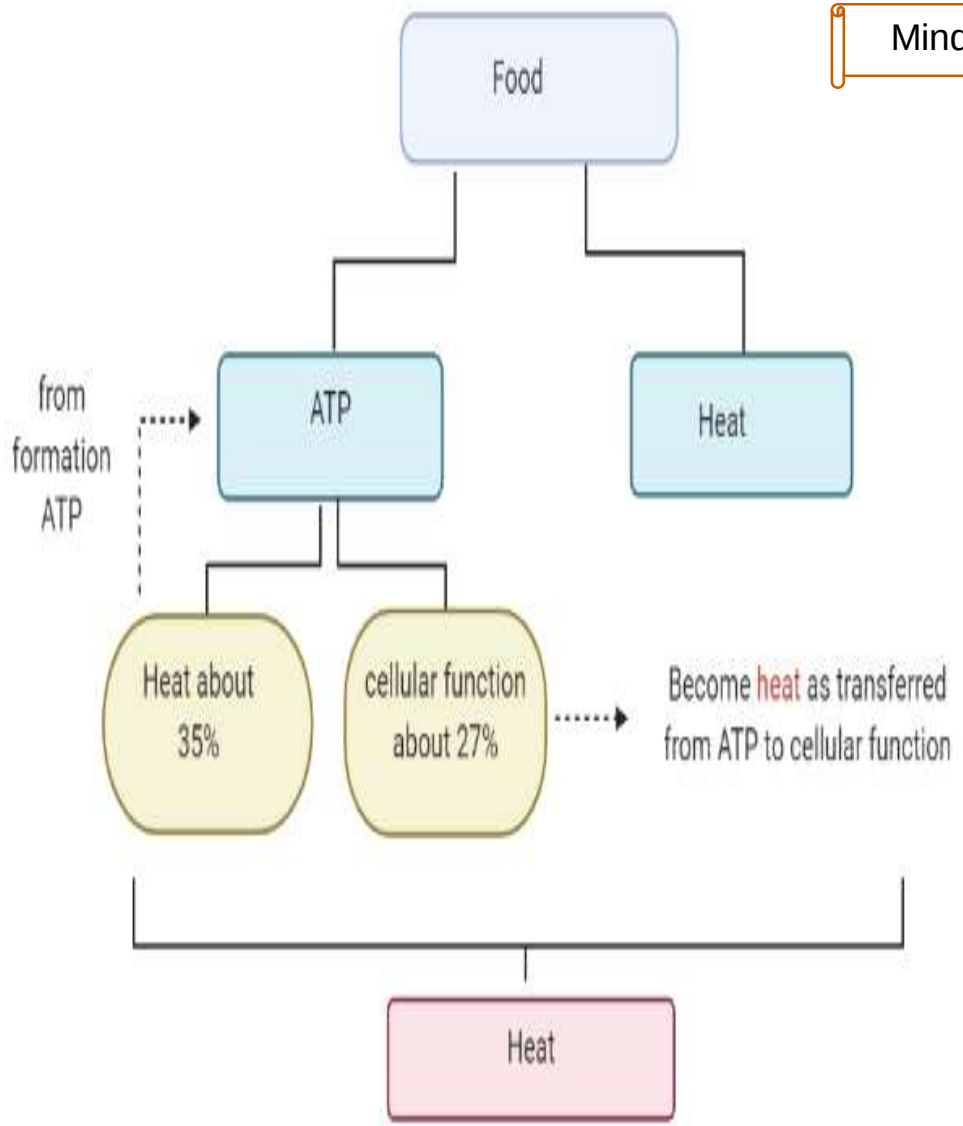
The metabolism of the body simply means all the chemical reactions in all the cells of the body.

The metabolic rate : the rate of heat liberation during chemical reactions .

Mind map 1

Energy Output

- **Heat** Is the end product of almost all the energy released in the Body.
- Not all the energy in foods is transferred to ATP, but a large portion of this energy becomes heat.
- About 35% of the energy in foods becomes heat during ATP formation.
- Additional energy becomes heat as it is transferred from ATP to the cells functions, at optimal conditions, no more than 27% of all the energy from food is finally used by the functional systems.
- When there is no external energy expenditure, all the energy released by the metabolic processes eventually becomes body heat.



Calorie and metabolic rate

Importance of calorie: It is a unit for expressing the quantity of energy released from the different foods in the body.

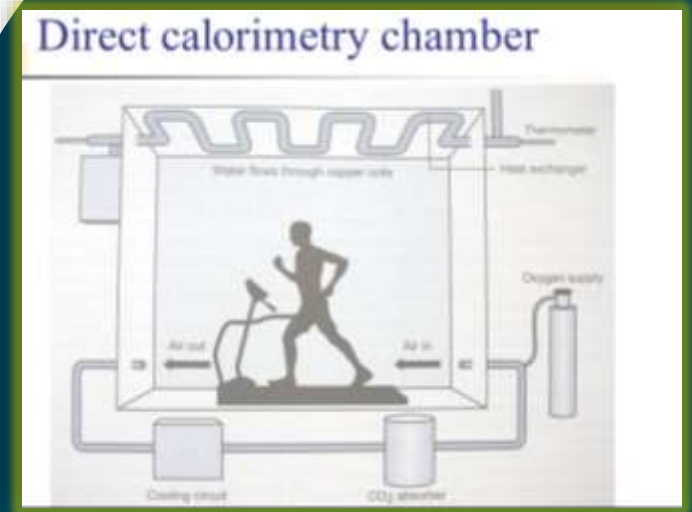
Definition of calorie :it is the unit used for:

1. 1 **c**alorie (**spelled with a small "c"** and often called a gram calorie) is the quantity of heat required to raise the temperature of 1 gram of water 1°C. it is much too small unit.
2. **C**alorie (**spelled with a capital "C"** and often called a kilocalorie, which is equivalent to 1000 calories)is the unit ordinarily used when discussing energy metabolism.

Measurement of the Whole-Body Metabolic Rate

A) Direct Calorimetry Measures Heat Liberated From the Body:

- It is measuring the total quantity of heat liberated from the body in a given time.
- Done by heat measurement in a large constructed calorimeter (insulate)
- Direct calorimetry is physically difficult to perform and is used only for research purposes.

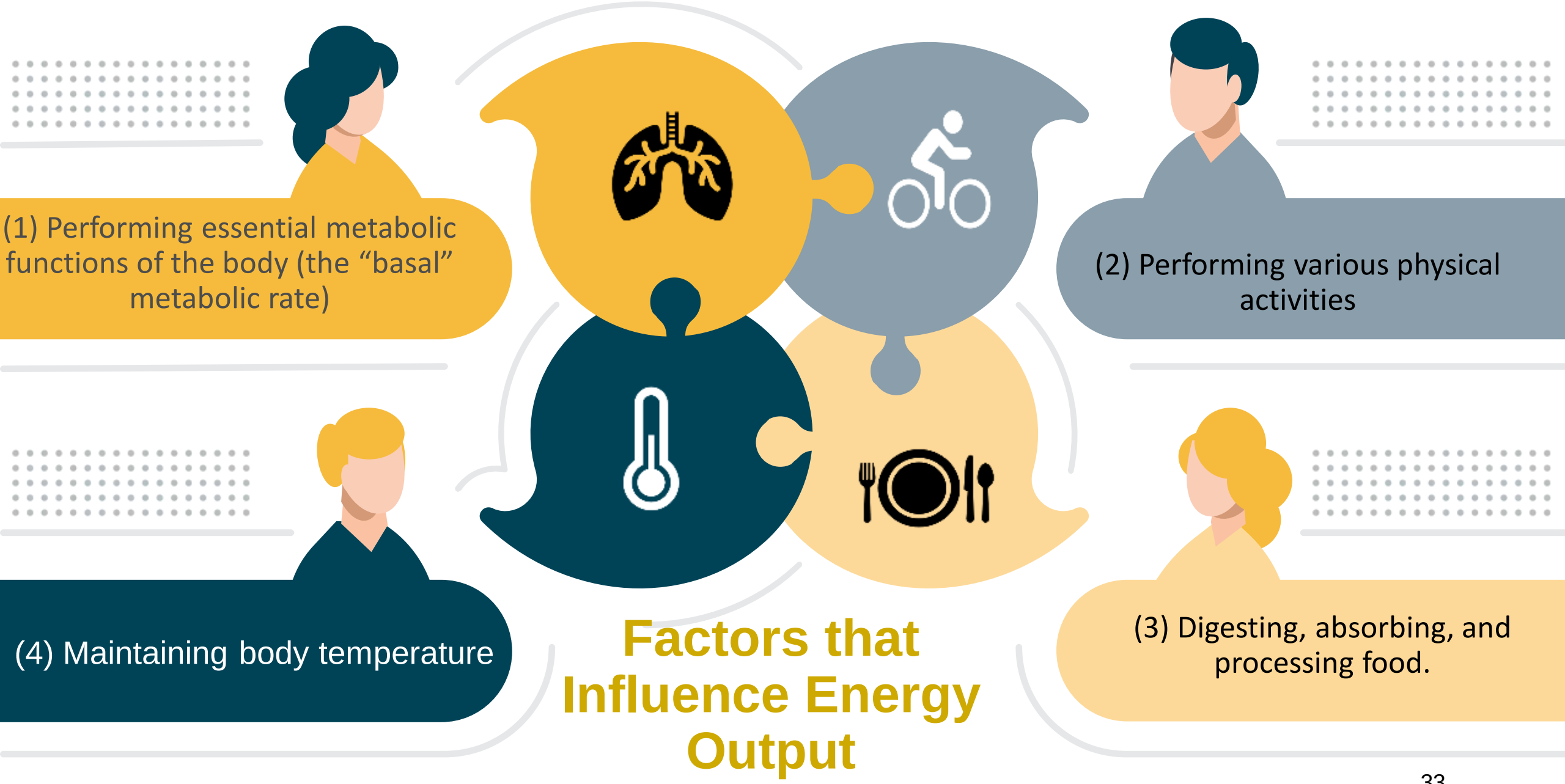


Measurement of the Whole-Body Metabolic Rate cont.

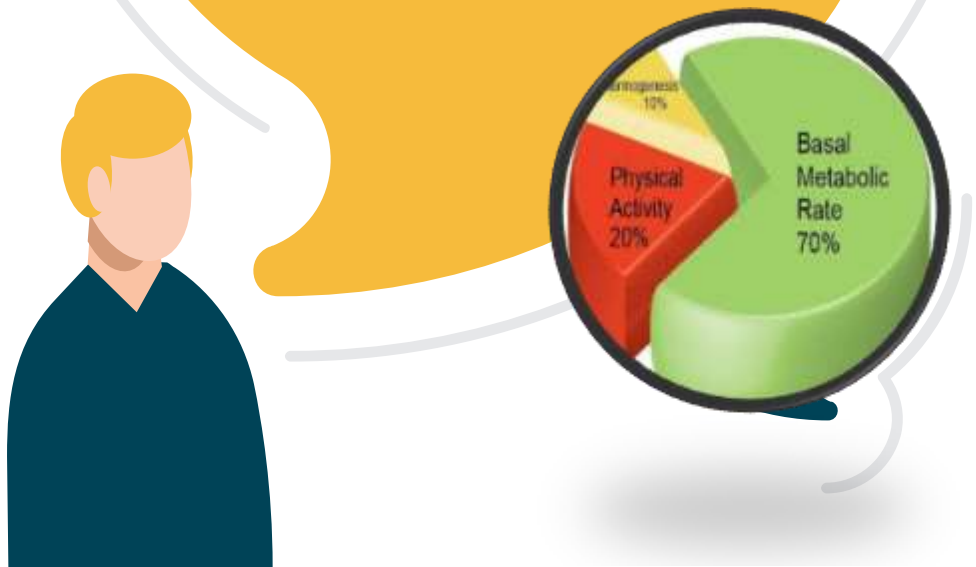
- **B) Indirect Calorimetry—The "Energy Equivalent" of Oxygen.**
- 95 % of the energy derived from reactions of oxygen with the different foods ,so whole BMR can be calculated using rate of oxygen utilization.

When 1 liter of oxygen is metabolized with			
glucose	starches	fat	protein
5.01 Calories of energy are released	5.06 Calories of energy are released	4.70 Calories of energy are released	4.60 Calories of energy are released

- **Energy equivalent of oxygen:** the quantity of energy liberated per liter of oxygen used in the body averages about 4.825 Calories


(1) Performing essential metabolic functions of the body (the “basal” metabolic rate)
(2) Performing various physical activities
(4) Maintaining body temperature
(3) Digesting, absorbing, and processing food.
Factors that Influence Energy Output

Components of Total Energy Expenditure (TEE)



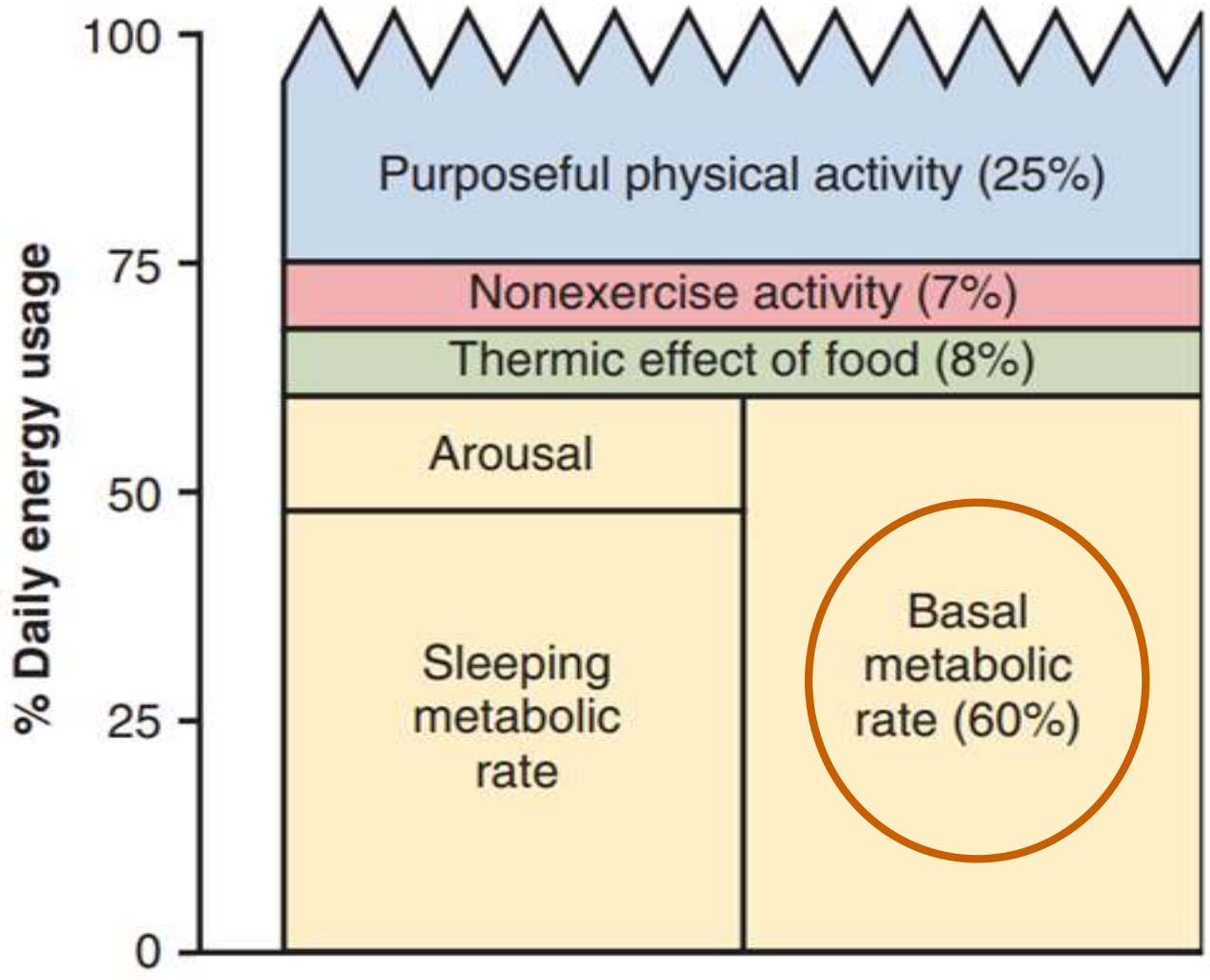


Figure 73-3. Components of energy expenditure.

Basal Metabolic Rate (BMR)

- Metabolic rate during basal condition.
- **BMR:** the minimum level of energy required for life or exist and maintain normal physiological functions.
- BMR is considered for by or used by essential activities of the central nervous system, heart, kidneys, and other organs.
- It accounts for about 50 - 70 % of the daily energy expenditure in most sedentary persons .
- The BMR normally averages about 65 to 70 Calories per hour in an average 70-kilogram man.

BMR calculation

- The usual method for determining BMR is to measure the rate of oxygen utilization over a given period under the following condition:

1.The person must not have eaten food for at least 12 hours.

2. Determined After a night of restful sleep.

3.No activity is performed for at least 1 hour before the test.

4.All factors that cause excitement must be eliminated.

5.The temperature of the air must be comfortable and between 25 - 30 C°.

6.No physical activity is permitted during the test.

Factor affecting the rate of BMR

1) Age :

- Much of the decline in BMR with increasing age is probably related to loss of muscle mass and replacement of muscle with adipose tissue, which has a lower rate of metabolism.

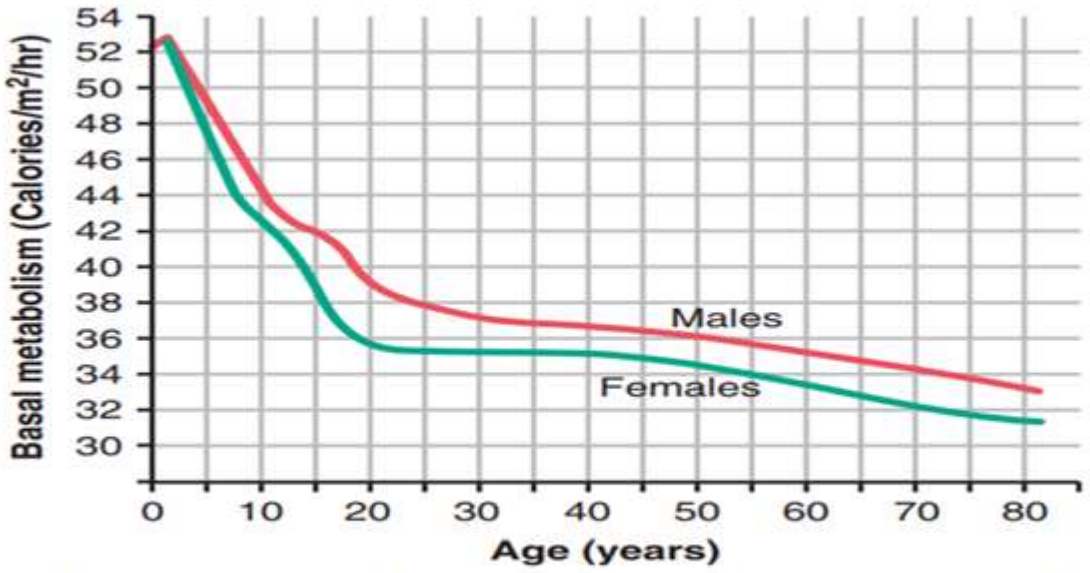


Figure 73-4. Normal basal metabolic rates at different ages for each sex.

Factor affecting the rate of BMR cont.

2) Body composition and sex :

- Skeletal muscle, even under resting conditions, accounts for 20 to 30% of the BMR. For this reason, BMR is usually corrected for differences in body size calculated from height and weight.
- Slightly lower BMRs in women, compared with men, are due partly to the lower percentage of muscle mass and higher percentage of adipose tissue in women .

Factor affecting the rate of BMR cont.

3) Fever Increases Metabolic Rate. Fever, regardless of its cause, increases the chemical reactions of the body by an average of about 120 % for every 10°C rise in temperature.

4) Sleep Decreases Metabolic Rate. The metabolic rate decreases 10 - 15 % below normal during sleep, due to two principal factors: (1) decreased tone of the skeletal musculature (2) and decreased activity of the central nervous system.

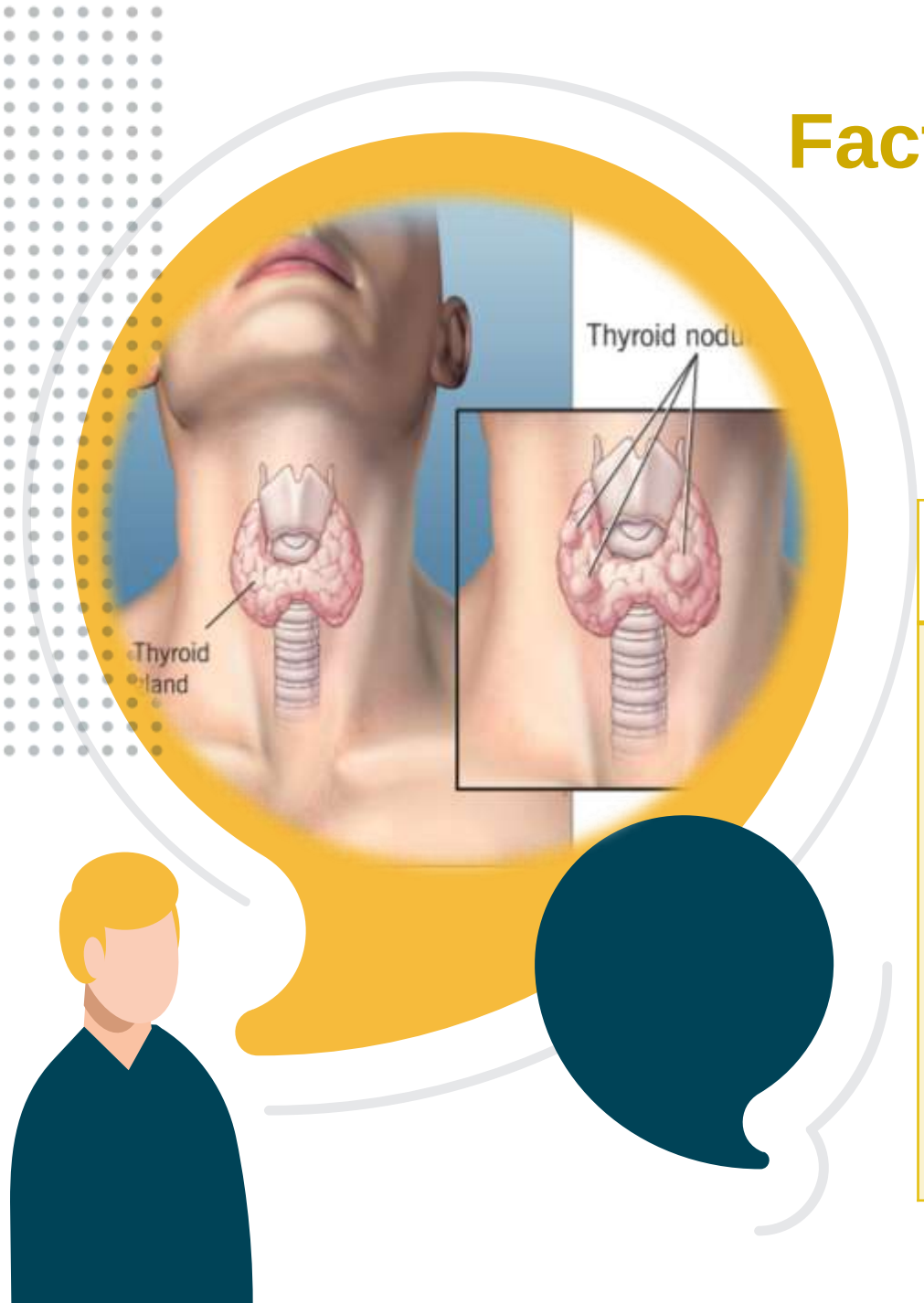
Factor affecting the rate of BMR cont.

5) Nutritional status:

Prolonged malnutrition decrease (20 – 30 %) metabolic rate because of the lack of food substances in the cells.

*In the final stages of any disease, it causes a marked decrease in metabolic rate, to the extent that the body temperature may fall several degrees shortly before death.

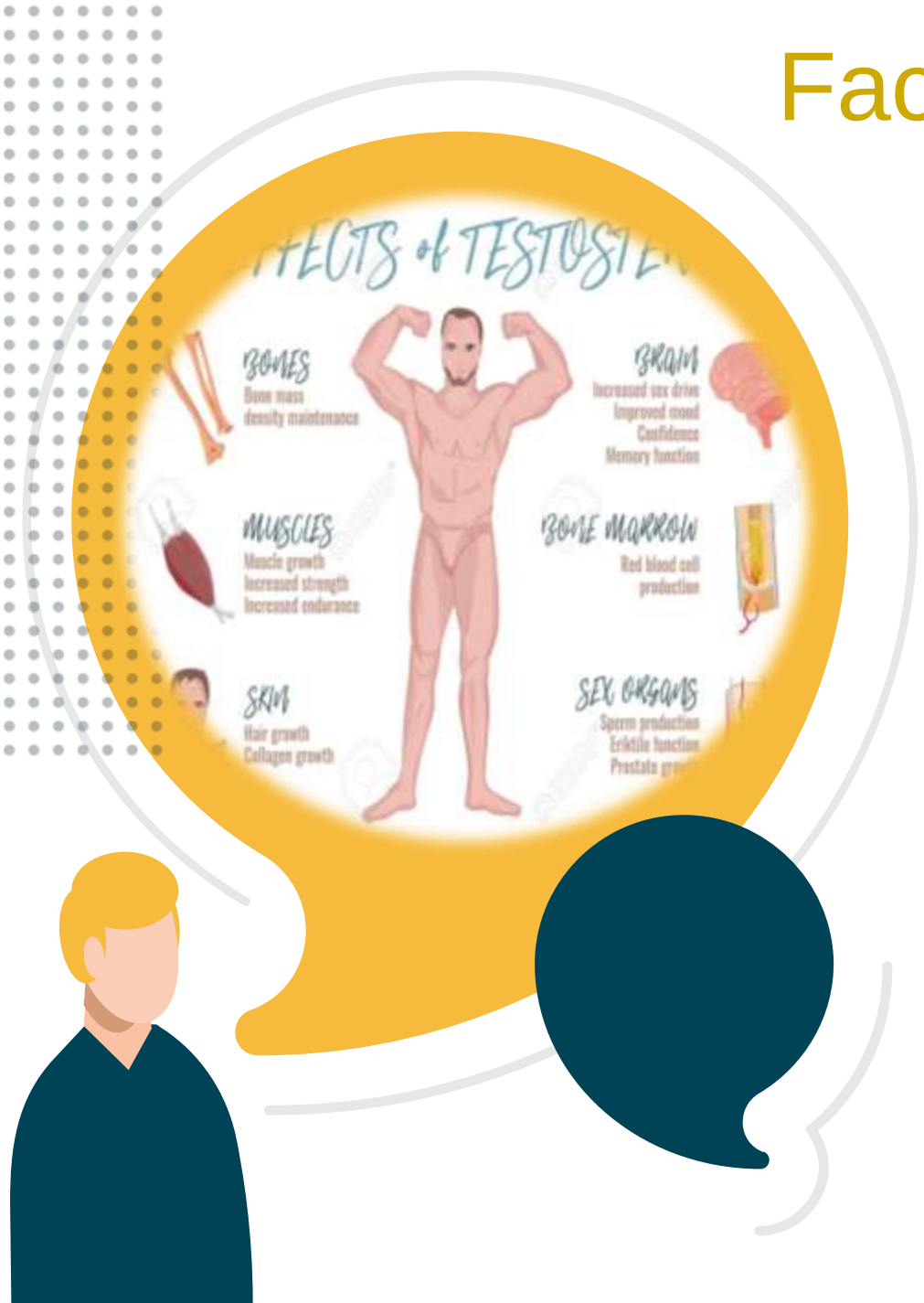
Factor affecting the rate of BMR cont.



6) Hormone status: Several hormonal factors influence BMR especially as the following:

Name of hormone	Effect of BMR	The role of the hormone in the rate of BMR
Thyroid Hormone	BMR is(↑) in hyperthyroidism and (↓) in hypothyroidism.	• Thyroxine increases metabolic rate. • Thyroid gland adaptation with increased secretion in cold climates and decreased secretion in hot climates contributes to BMR differences among people living in different geographic areas.

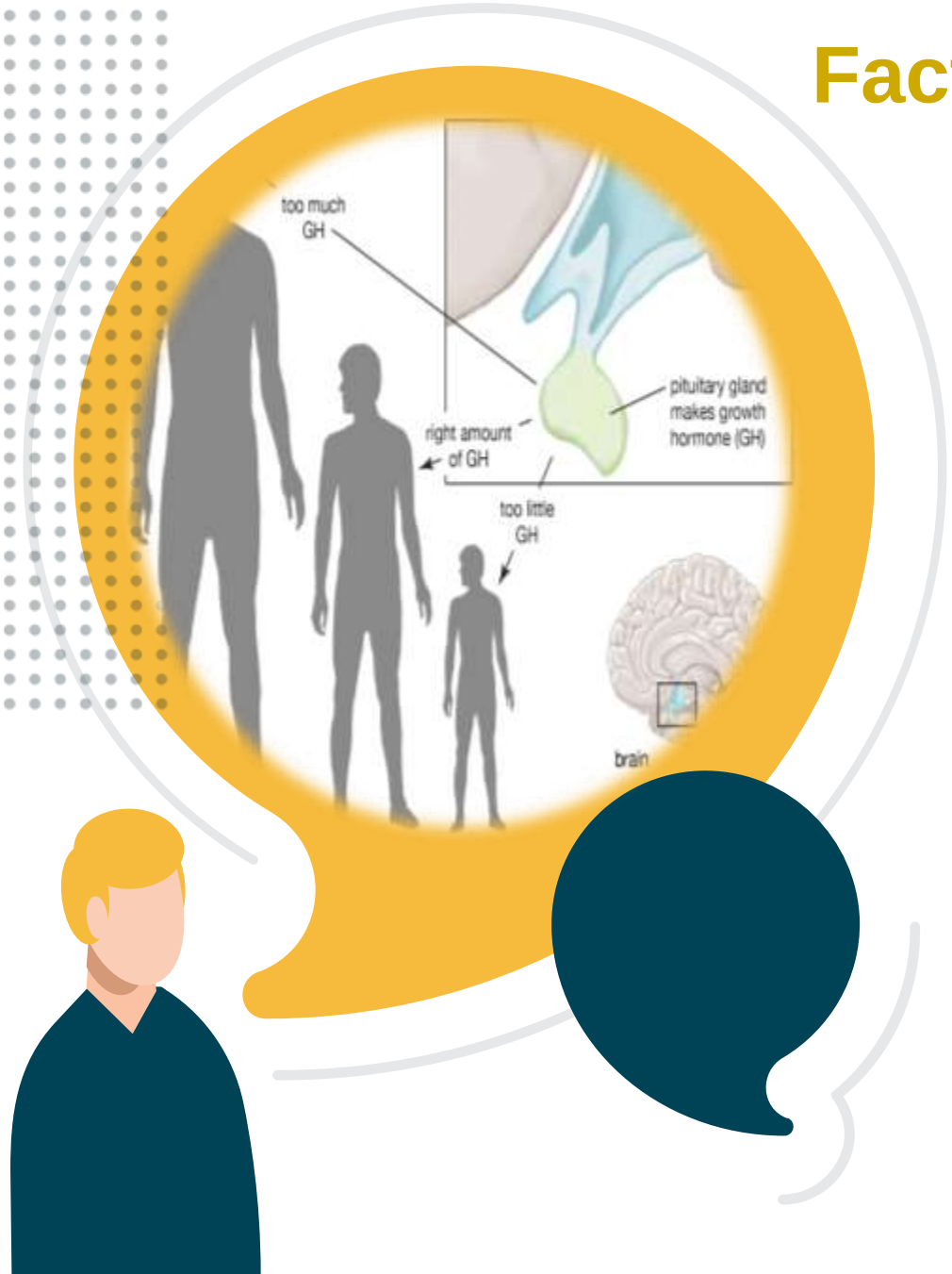
Factor affecting the rate of BMR cont.



6) Hormone status: Several hormonal factors influence BMR especially as the following:

Name of hormone	Effect of BMR	The role of the hormone in the rate of BMR
Testosterone hormone (male sex hormone)	BMR is(↑)	• The female sex hormones may increase the BMR a small amount. • The effect of testosterone is related to its anabolic effect to increase skeletal muscle mass.

Factor affecting the rate of BMR cont.



6) Hormone status: Several hormonal factors influence BMR especially as the following:

Name of hormone	Effect of BMR	The role of the hormone in the rate of BMR
Growth hormone	BMR is(↑)	• Growth hormone can increase the metabolic rate by stimulating cellular metabolism and by increasing skeletal muscle mass. • In adults with growth hormone deficiency, replacement therapy with recombinant growth hormone increases the basal metabolic rate by about 20%.

Mind map 2

Factor Affecting the Rate of BMR

- Nutritional status
  - Malnutrition decrease 20-30% of BMR
- Age
  - BMR decrease with increasing age
- Hormone
  - Thyroid Hormone increase BMR
  - Hormone testoterone increase BMR
  - Grouth hormone increase BMR
- Sleep
  - BMR decrease 10-20 % during sleep
- Body composition
  - BMR increase with increase muscle mass and decrease with adipos tissue
- Sex
  - BMR increase in man than women
- Fever
  - BMR increase with fever about 120 % for every 10 C rais in tempreture

Overall Energy Requirements for Daily Activities + Energy Used for Physical Activities

- The factor that most dramatically increases metabolic rate is strenuous exercise.
- Daily physical activities is normally about 25% of the total energy expenditure, but it depends on the type and amount of physical activity performed, this is important reason for the differences in caloric intake required to maintain energy balance.
- In general, over a 24-hours, a person performing heavy activity can utilize energy between 6000 - 7000 Calories, or about 3.5 times the energy used under conditions of no physical activity.

Overall Energy Requirements for Daily Activities + Energy Used for Physical Activities cont.

- In sedentary individuals who perform little or no daily exercise, energy is required on natural physical activity to maintain muscle tone and body status, these non-exercise activities account for about 7 % of a person's daily energy usage.
- Industrialized countries where food supplies are usually abundant and physical activity is often poor, caloric consumption often periodically exceeds energy expenditure, and excess energy is primarily stored as fat.

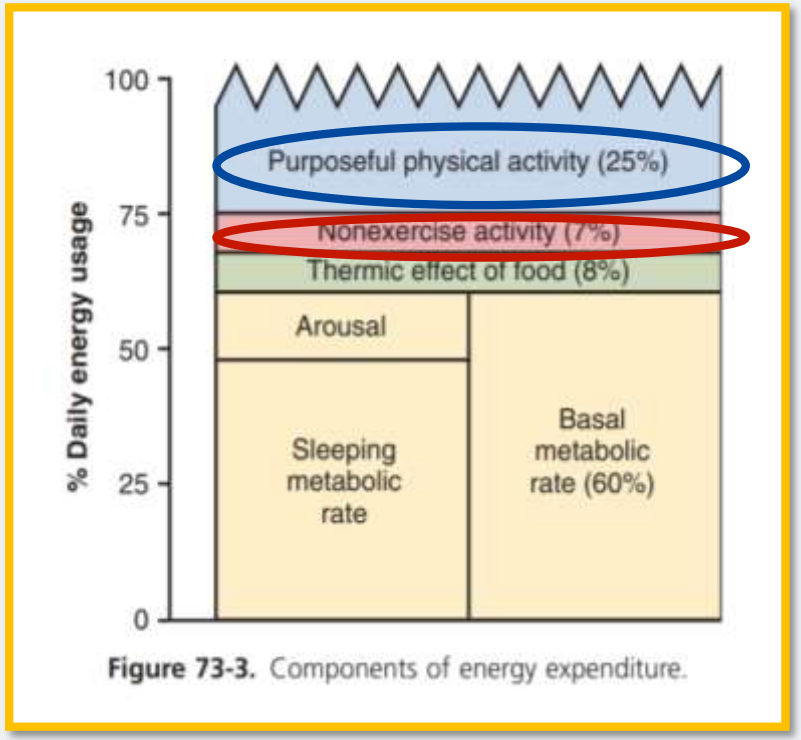


Figure 73-3. Components of energy expenditure.

Overall Energy Requirements for Daily Activities + Energy Used for Physical Activities cont.

Table 73-1 Energy Expenditure During Different Types of Activity for a 70-Kilogram Man

Form of Activity	Calories per Hour
Sleeping	65
Awake lying still	77
Sitting at rest	100
Standing relaxed	105
Dressing and undressing	118
Typing rapidly	140
Walking slowly (2.6 miles per hour)	200
Carpentry, metalworking, industrial painting	240
Sawing wood	480
Swimming	500
Running (5.3 miles per hour)	570
Walking up stairs rapidly	1100

Extracted from data compiled by Professor M.S. Rose.

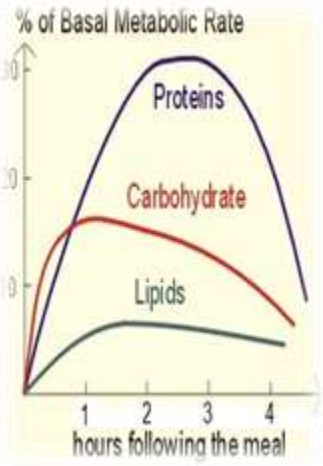
70 KG (lying in bed all day)

Consume about 1650 energy calories

Eating and digesting food raises the amount of energy used

The same man lying in bed and consuming a reasonable diet increases the amount 1850 Calories per day.

Energy Used for Processing Food



- After a meal is ingested, the metabolic rate increases as a result of the different chemical reactions associated with digestion, absorption, and storage of food in the body.
- This increase is called the *thermogenic effect of food (TEF)* because these processes require energy and generate heat.

Energy Used for Processing Food cont.

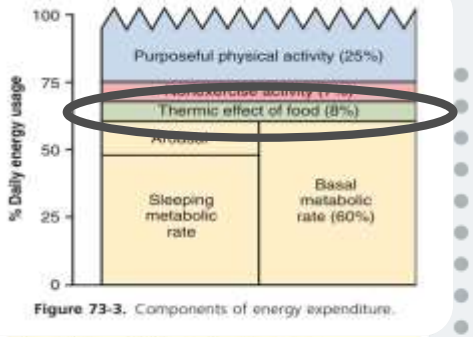
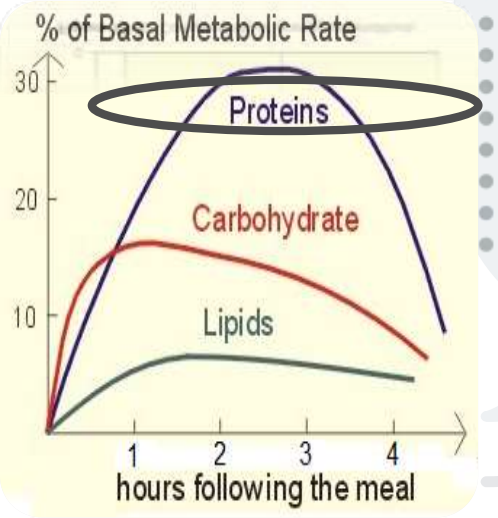


Figure 73-3. Components of energy expenditure.



- After a meal that contains carbohydrates or fats, the metabolic rate increases about 4 % .
- For meal high in protein, the metabolic rate increases about 30 % for 3 to 12 hours. This effect of protein on the metabolic rate is called the *specific dynamic action* of protein.
- The thermogenic effect of food accounts 8 % of the total daily energy expenditure in many persons.

Energy Used for Non-shivering Thermogenesis
(Role of Sympathetic Stimulation)

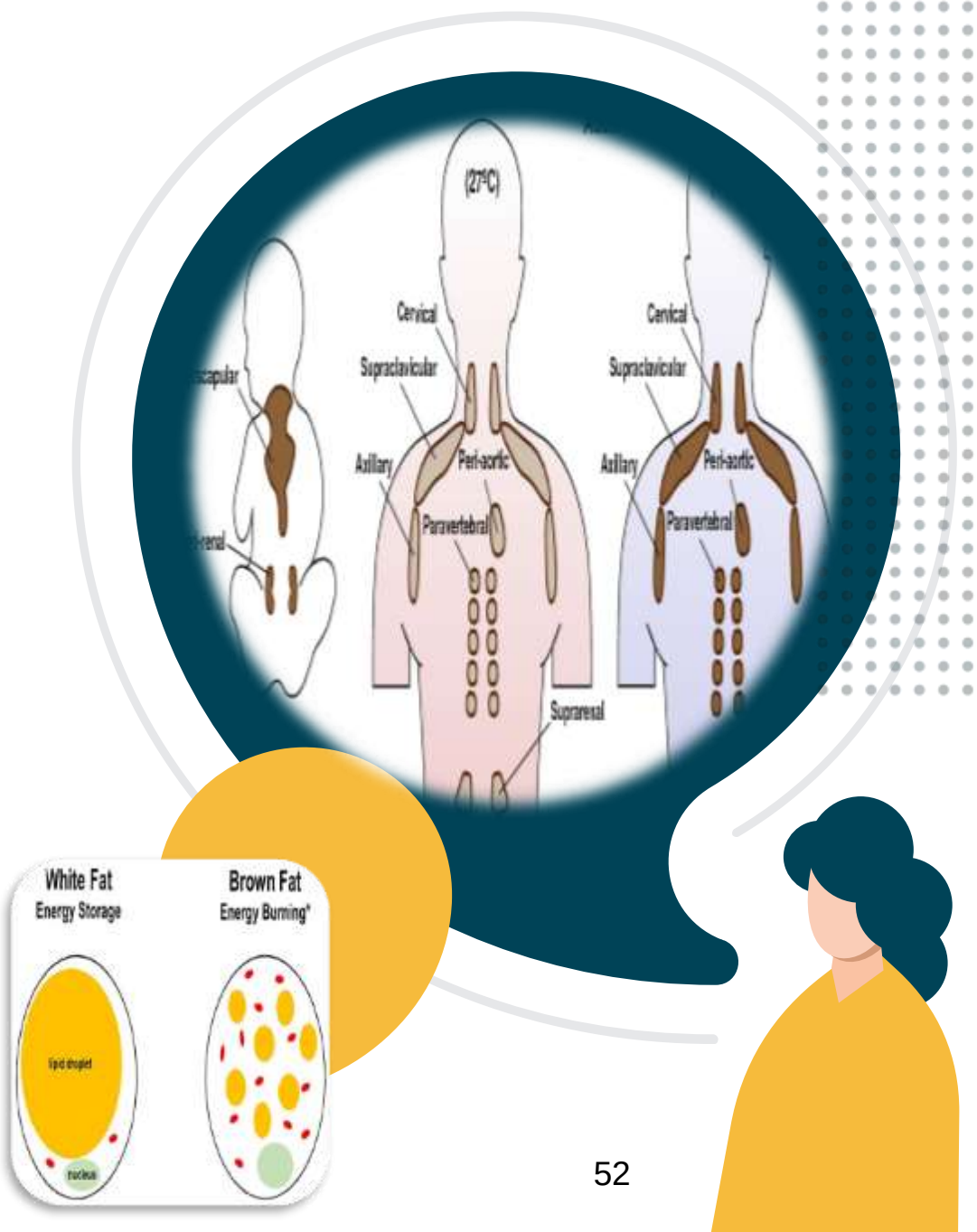
- **physical work** and the **thermogenic effect of food** cause liberation of heat, these mechanisms are not aimed primarily at regulation of body temperature.
- Shivering provides a regulated ways of producing heat by increasing muscle activity in response to cold stress.

Energy Used for Non-shivering Thermogenesis cont.

- Non-shivering thermogenesis, can also produce heat in response to cold stress. This type of thermogenesis is stimulated by sympathetic nervous system activation, which releases norepinephrine and epinephrine, which in turn increase metabolic activity and heat generation.

Energy Used for Non-shivering Thermogenesis cont.

- In certain types of fat tissue, called brown fat, which contains large numbers of mitochondria and many small globules, sympathetic nervous stimulation causes liberation of large amounts of heat but almost no ATP, so almost all the released oxidative energy immediately becomes heat.
- An infant has large brown fat and sympathetic stimulation increase of Metabolism about 100%, while Adult human with no brown fat, has less than 15 % of this mechanism.



Energy Used for Non-shivering Thermogenesis cont.

- Non-shivering thermogenesis is a buffer against obesity.
- Sympathetic nervous system activity is increased in obese persons who have a continues high caloric intake, this mechanism is unclear, it might be because the effects of increased leptin, which activates pro-opiomelanocortin neurons in the hypothalamus.
- Sympathetic stimulation, by increasing thermogenesis, helps to limit excess weight gain.

Mind map 3

Regulated of body temperature in cold clime

Shivering

response to cold stress

producing heat by increasing muscle activity

Non-shivering

response to cold stress

producing heat by sympathetic nervous system activation, which releases norepinephrine and epinephrine

Mind map 4

Summary of Metabolic Rate

Metabolic rate

DIFINITION

The rate of heat liberation during chemical reactions

MEASUREMENT OF METABOLIC RATE

1. Direct Calorimetry
2. Indirect Calorimetry

CALORI AND METABOLIC RATE

- calorie(spelled with a small "c" is a small unit to use when referring to energy in the body.
- Calorie (spelled with a capital "C" is the unit ordinarily used when discussing energy metabolism.

COMPONENTS COMPONENTS OF TOTAL ENERGY EXPENDITURE (TEE)

- Basal Metabolic Rate (50-70%) of daily energy .
- Physical Activities (25%) of daily energy .
- non-exercise Activities (7 %) of daily energy .
- Thermic Effect of Food (8 %) of daily energy .

FACTOR AFFECTING THE RATE OF BMR

- Age
- Body Composition and Sex
- Fever
- sleep
- Nutritional status
- Hormone status (Thyroid Hormone - hormone Testosterone - Growth hormone)

CONDITIONS TO BE CALCULATING THE BMR

- do not eat food for12 hours.
- determined after a night of restful sleep
- No strenuous exercise happens 1 hour before the exam.
- All factors that cause excitement must be eliminated.
- The air temperature must be comfortable and between 25-30°C.
- No physical activity during the test.

Thank You for listening ♥