ENERGETIC METABOLISM

= summary of all chemical (and physical) processes included in:

1. **Production of energy from internal and external sources**
2. **Synthesis** and **degradation** of structural and functional tissue components
3. Excretion of **waste products** and **toxins** from body

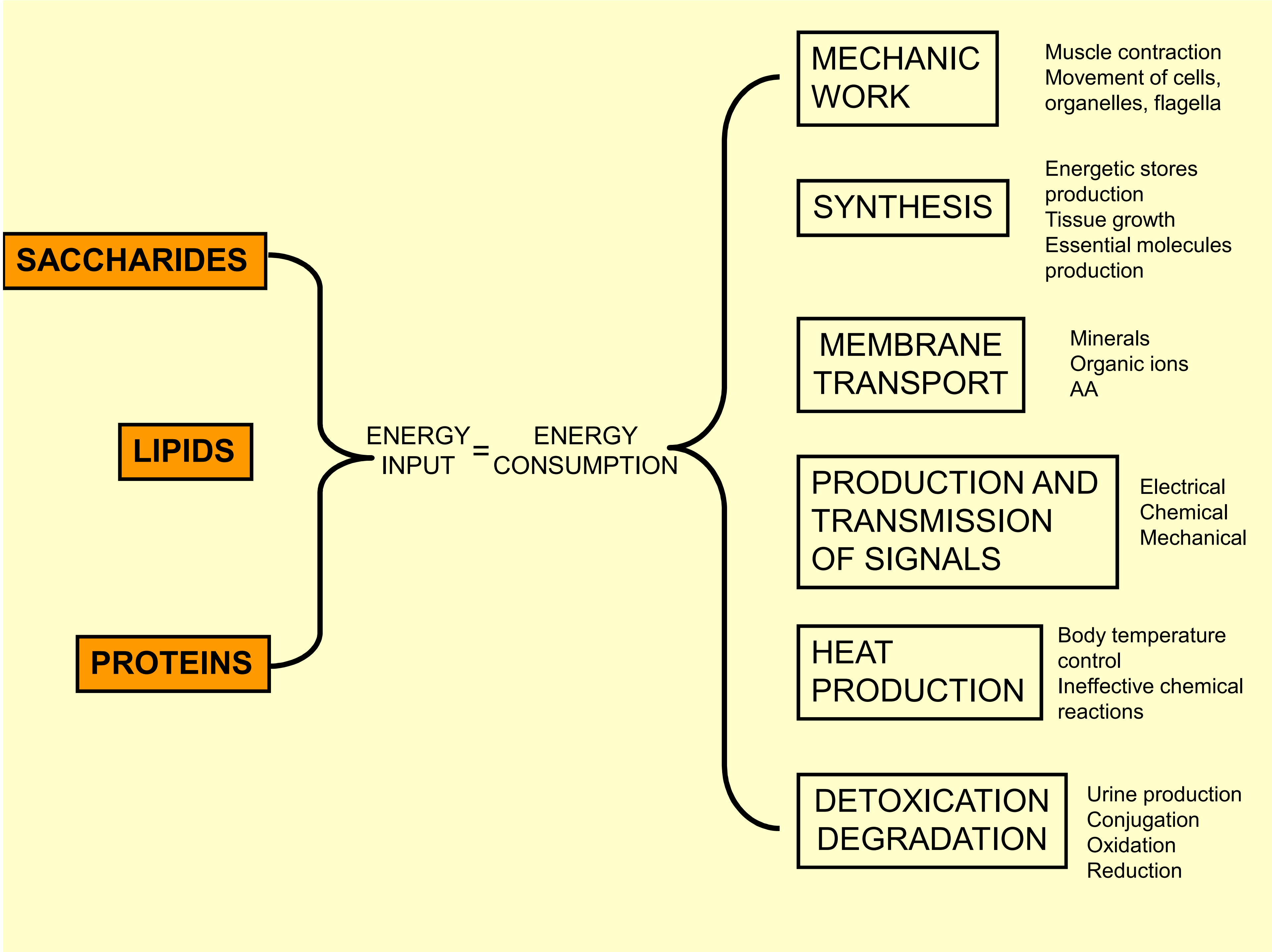
Metabolic speed: amount of energy released per unit of time

Calorie (cal) = amount of thermal energy, necessary for warming up 1g of water for 1°C, from 15°C to 16°C

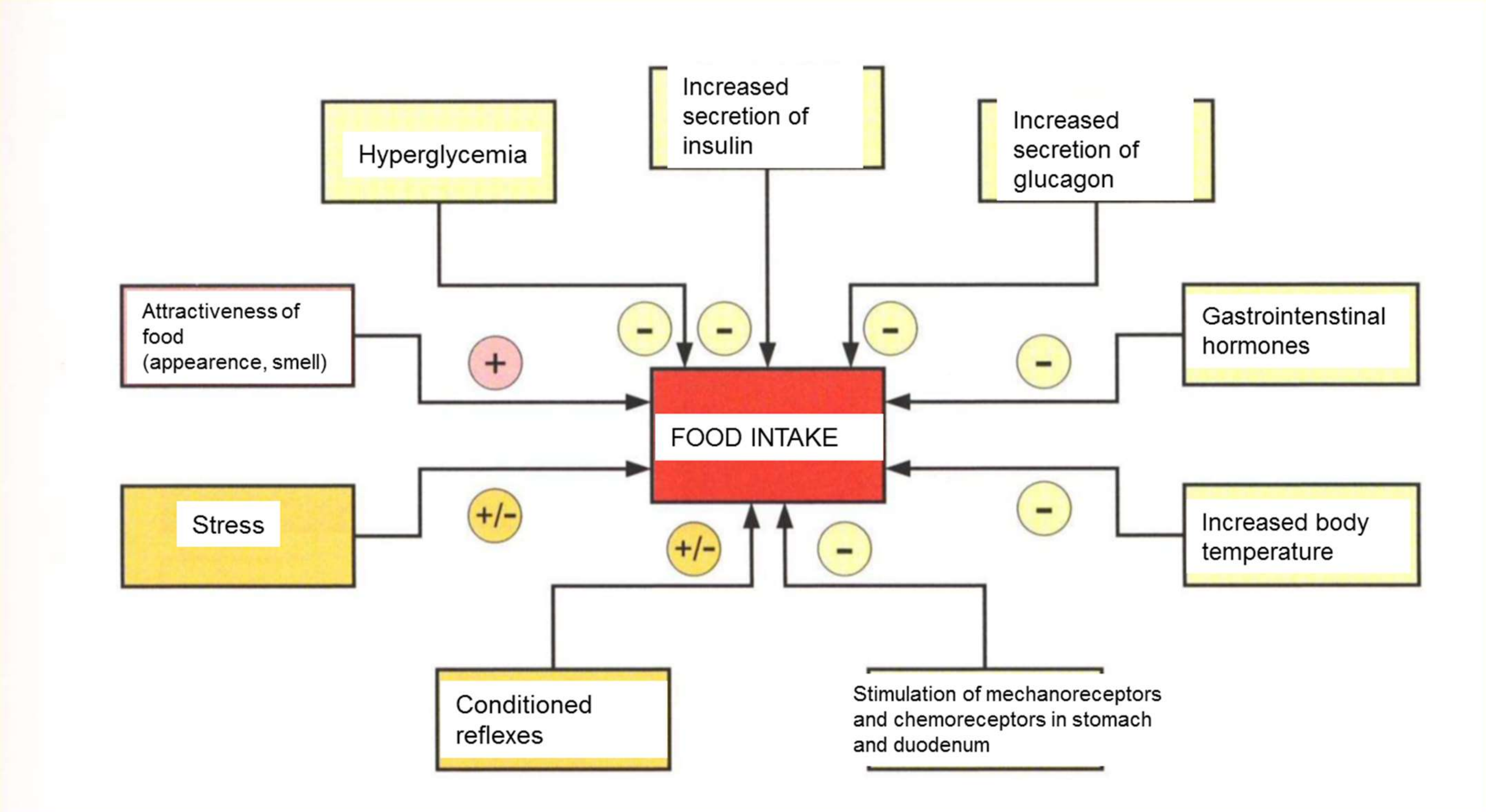
METABOLISM

- Complex, slow process = CATABOLISM = release of energy in small quantities
- Energy storage in the energy-rich phosphate compounds and in the form of proteins, fats and complex carbohydrates (synthesized from simpler molecules).
- Creation of these compounds = ANABOLISM (energy is consumed).

- Calorie (cal, small calorie, gram calorie)
- Kilocalorie = kcal = 1000 cal = 4,18 kJ
- Joul = J = 0,239 cal
- Kilojoul = kJ = 1000 J


SACCHARIDES
LIPIDS
PROTEINS
ENERGY INPUT = ENERGY CONSUMPTION
MECHANIC WORK
Muscle contraction
Movement of cells, organelles, flagella
SYNTHESIS
Energetic stores production
Tissue growth
Essential molecules production
MEMBRANE TRANSPORT
Minerals
Organic ions
AA
PRODUCTION AND TRANSMISSION OF SIGNALS
Electrical
Chemical
Mechanical
HEAT PRODUCTION
Body temperature control
Ineffective chemical reactions
DETOXICATION DEGRADATION
Urine production
Conjugation
Oxidation
Reduction

regulation of food intake



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I. thermodynamic law:

At steady state, input of energy equals to its expenditure

Input $\longleftrightarrow$ stores

Expenditure of energy = external work + energy stores + heat

Intermediate stages: various chemical, mechanical and thermal reactions

ENERGY INTAKE (INPUT)

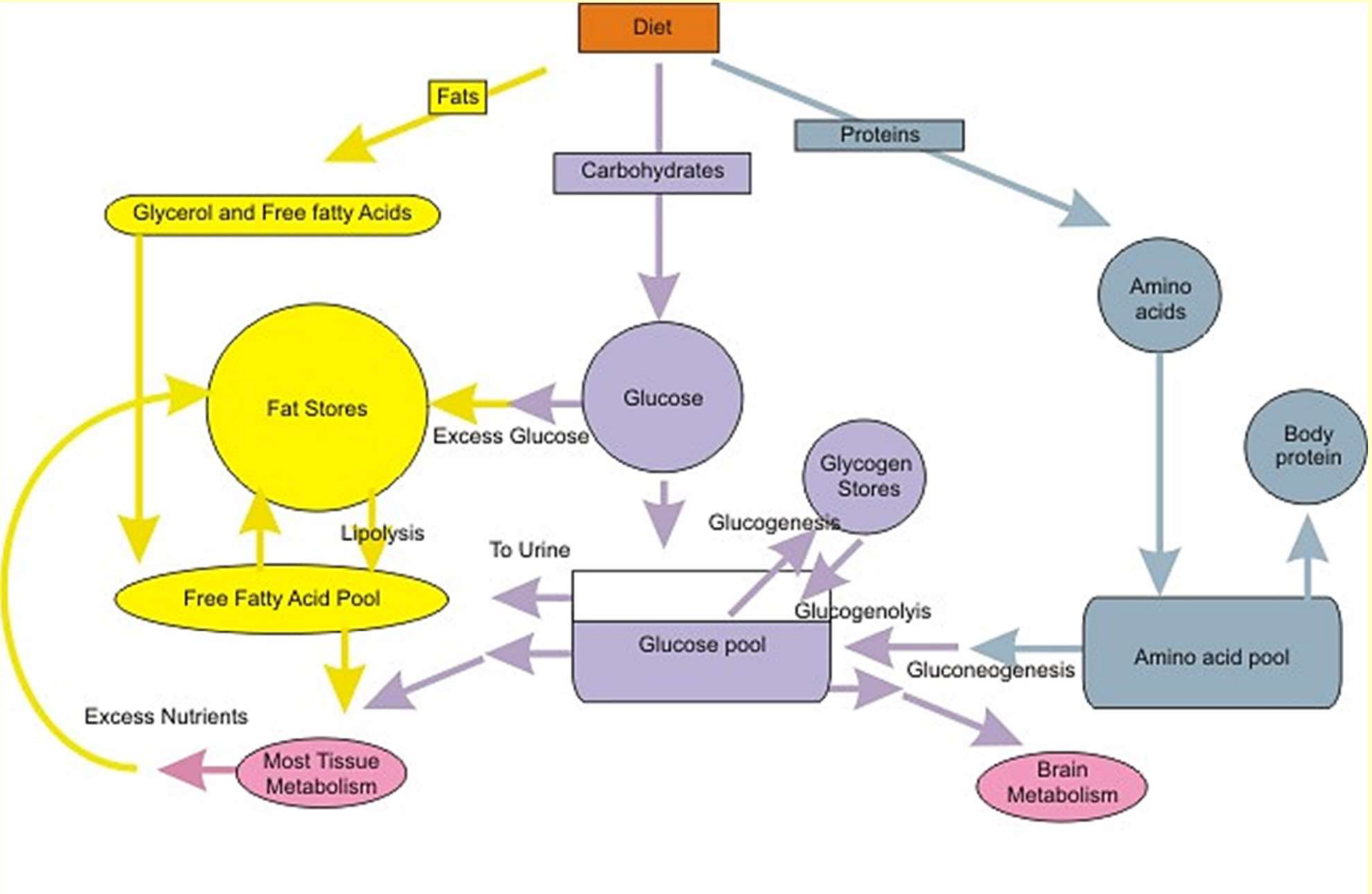
Saccharides, lipids, proteins

Burning releases: 4.1kcal/g, 9.3kcal/g, 5.3kcal/g (4.1 in body) 1kcal=4184J

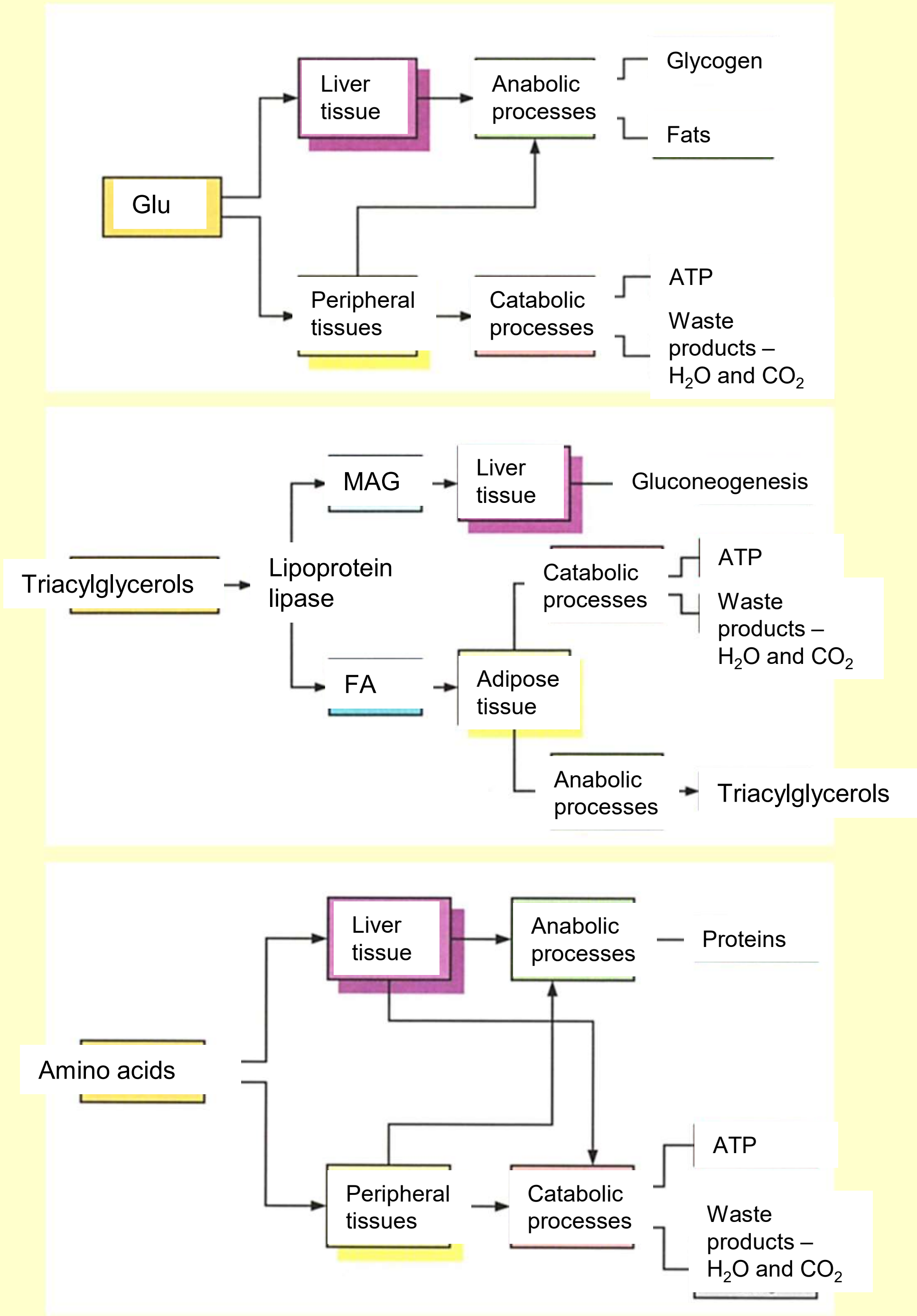
Conversion of proteins and saccharides to lipids – effective storage of the energy

Conversion of proteins to saccharides – need of „fast“ energy

BUT: there is no significant conversion of lipids to saccharides



Metabolism Summary



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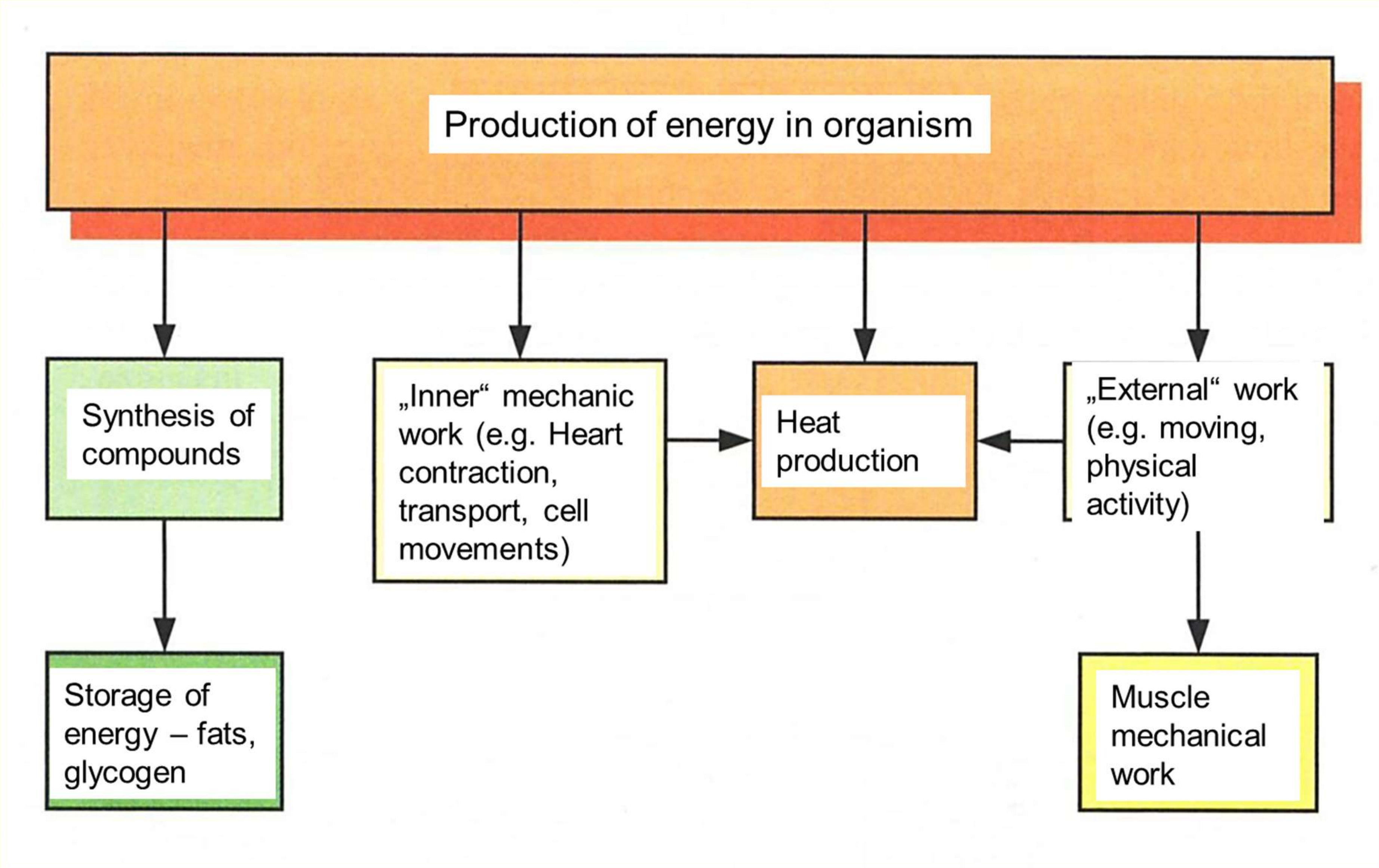
ENERGY OUTPUT

1. **At rest:** basal metabolism; 8 000 kJ / day; 200-250 ml O_2/min; directly depends on body mass and surface; decreases with age; increases with ambient temperature; decreases by 10-15% during sleep; genetically determined **75%BM**
2. **After meal:** slight increase in energetic output – **specific dynamic effect** – e.g. for glycogen formation **7%BM**
3. **Facultative thermogenesis:** non-shivering
4. **In sitting people:** spontaneous physical activity **18%BM**
5. **During exercising:** energetically most demanding; individual; changes according to season



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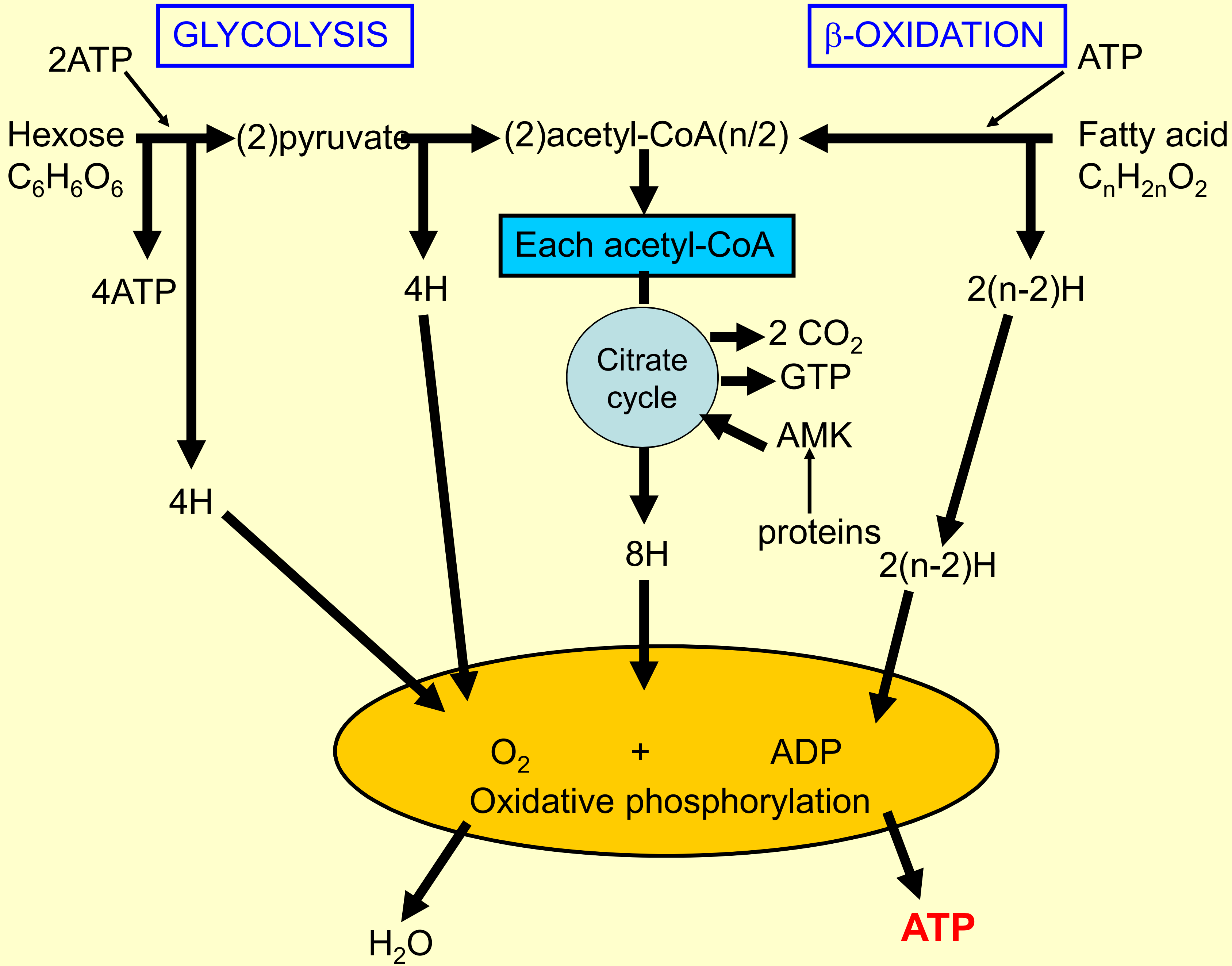
ENERGY PRODUCTION



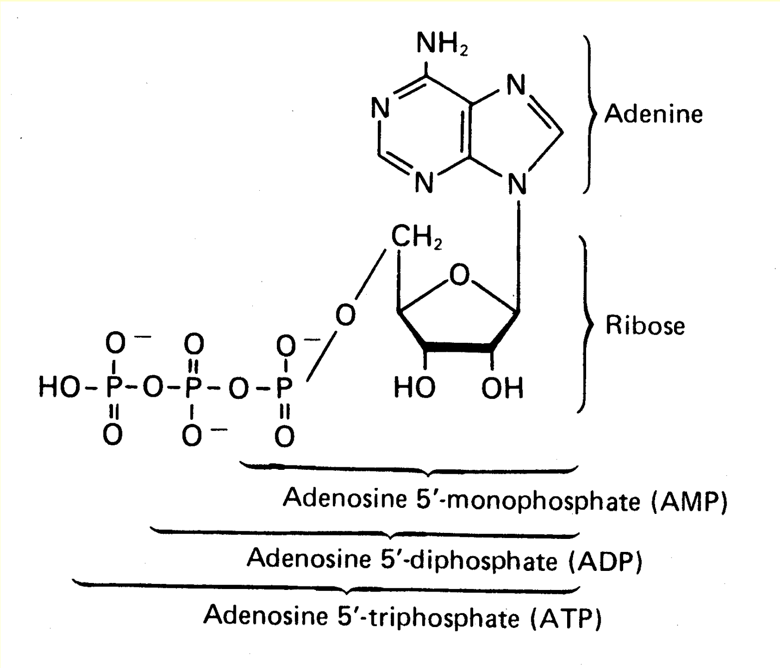
•Energy **stores**: ATP, creatinphosphate, GTP, CTP (cytosin), UTP (uridin), ITP (inosin)

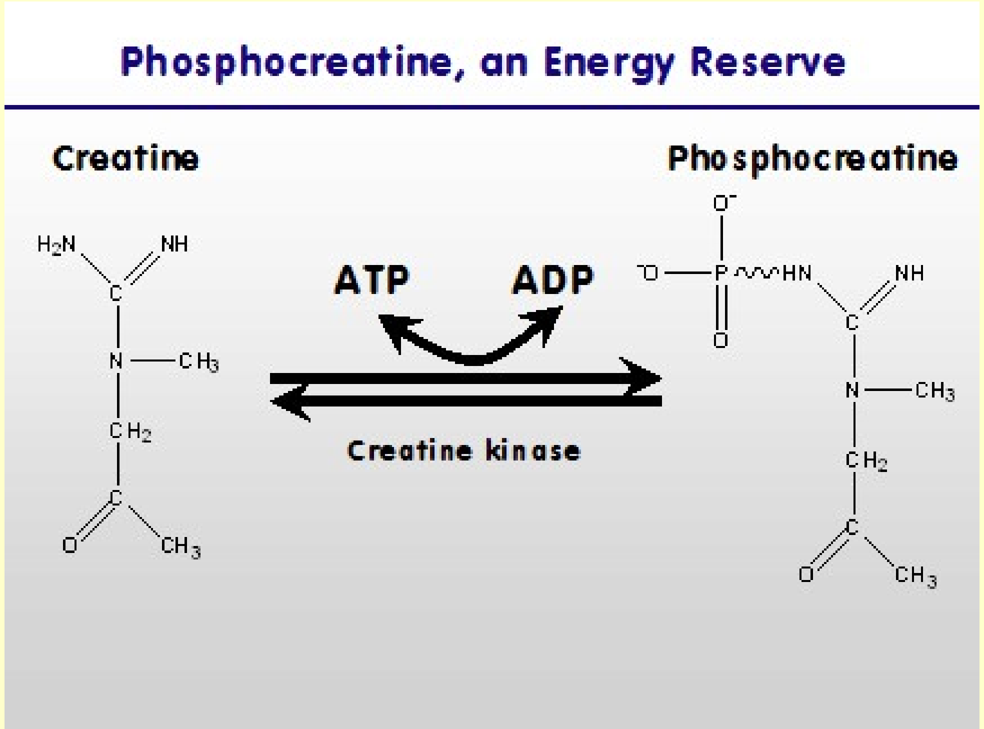
•Macroergic bond – 12kcal/mol

•Efficiency is not 100% - 18kcal of substrate to 1 bond in ATP

•Daily: 63 kg of ATP (128 mol)

•Glycolysis: only short-lasting source of energy (2 pyruvates – only approx. 8% of glucose energy); supply of glucose is limited, lactate

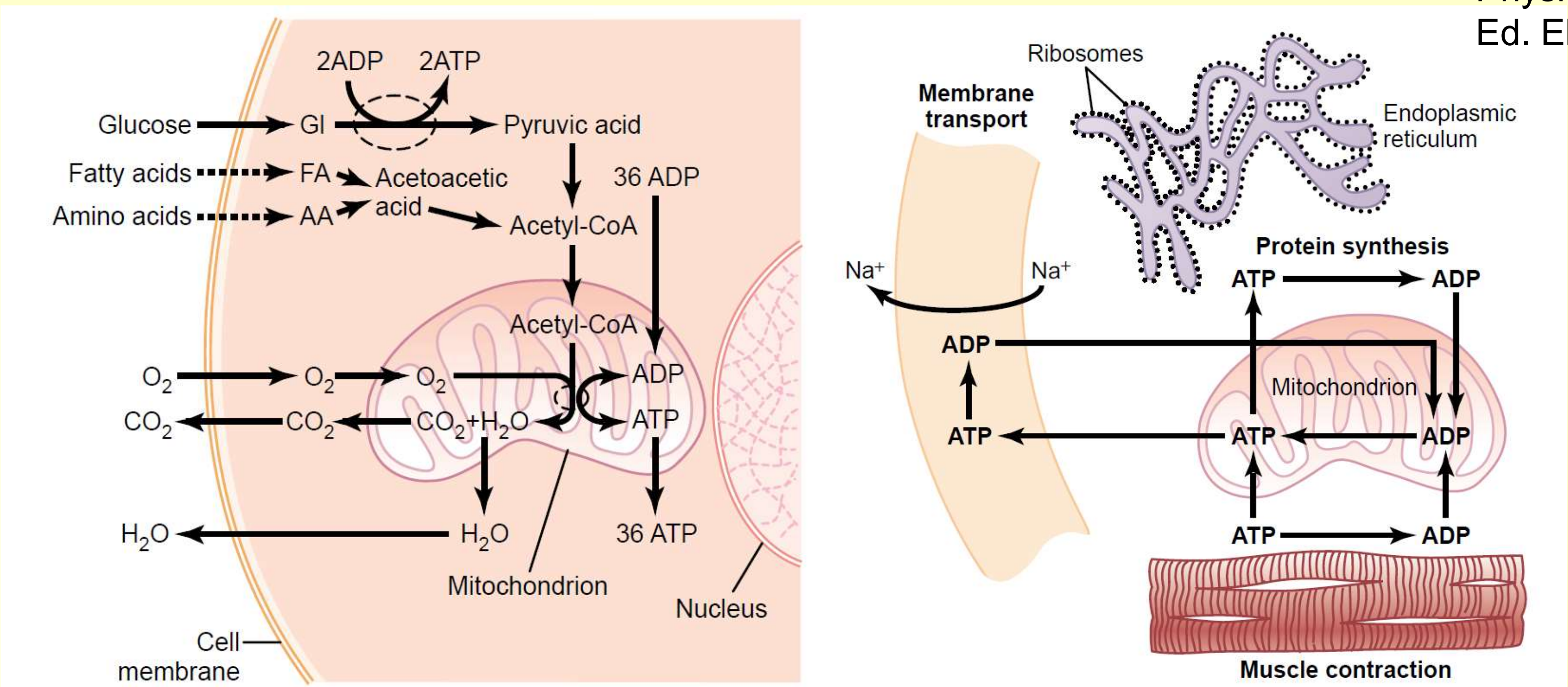




ATP

- Production of ATP mainly in mitochondria (up to 95%)
- Central role of acetyl-CoA and Krebs cycle
- Highly reactive hydrogen atoms = used for the conversion of ADP to ATP
- Chemiosmotic mechanism of ATP production

Guyton and Hall Textbook of Medical Physiology. 12th Ed. Elsevier 2006



Use of ATP in cells

- Membrane transport (Na^+, K^+, Ca^{2+},Mg^{2+}, phosphate, Cl^-, urate, hydrogen ions, specific types of transport – Glu, AAs, acetoacetate) – 80 % in some types of cells
- Synthesis of chemical compounds (phospholipids, cholesterol, purine and pyrimidine bases, proteins, urea – detoxifying function-ammonia)
  - In some types of cells up to 75 %
  - 500 – 5000 cal for creation of 1 M of protein (peptide bonds)
  - Synthesis of Glu from lactate and FA from acetyl-CoA
- Mechanic work
  - Role of myosin and conversion of ATP to ADP
- Secretion of glands
- Neurotransmission

Regulation of ATP production

- Oxidative phosphorylation
- Flavoprotein-cytochrome system
  - Transport of protons across the inner mitochondrial membrane, creation of electrochemical potential and transport of protons back into the matrix – role of ATP synthase
  - Regulation:
    - Consumption of ATP in tissues (OP increases with increasing ATP consumption)
    - Rate of uptake of fats, lactate, and glucose into mitochondria
    - Availability of oxygen – mitochondria under basal condition consume 90% of oxygen, 80% is connected with the synthesis of ATP
- Oxidation at the substrate level
  - Production of ATP at processes that release large amounts of energy

ATP Production

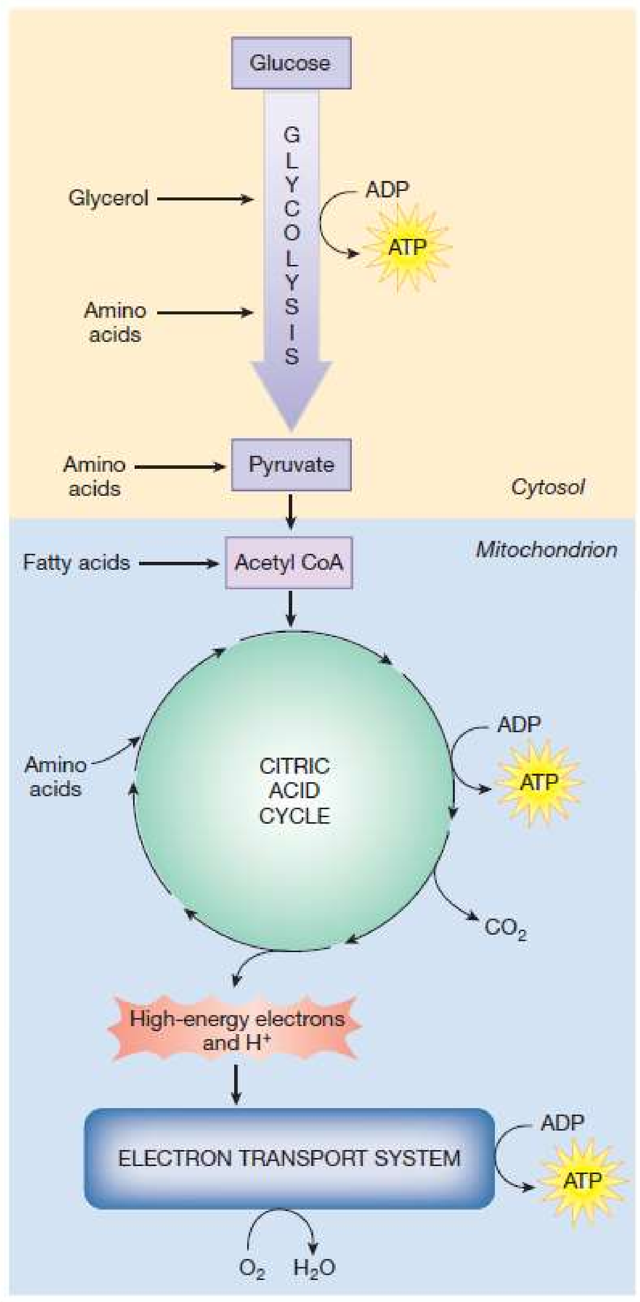
The catabolic pathways that extract energy from biomolecules and transfer it to ATP are summarized in this overview figure of aerobic pathways. Aerobic production of ATP from glucose commonly follows two pathways: **glycolysis** and the **citric acid cycle**. Each of these pathways produces small amounts of ATP directly, but their most important contributions to ATP synthesis are high-energy electrons carried by NADH and $FADH_2$ to the electron transport system in the mitochondria.

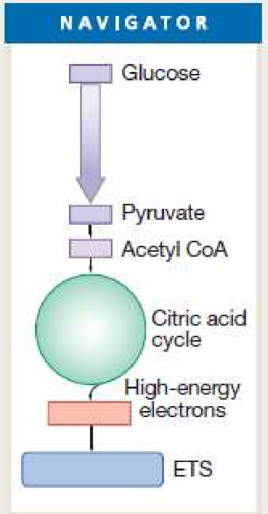
The energy production from one glucose molecule can be summarized in the following two equations.

Aerobic Metabolism of Glucose

$$\text{Glucose} + O_2 + \text{ADP} + P_i \rightarrow CO_2 + H_2O + \text{ATP}$$

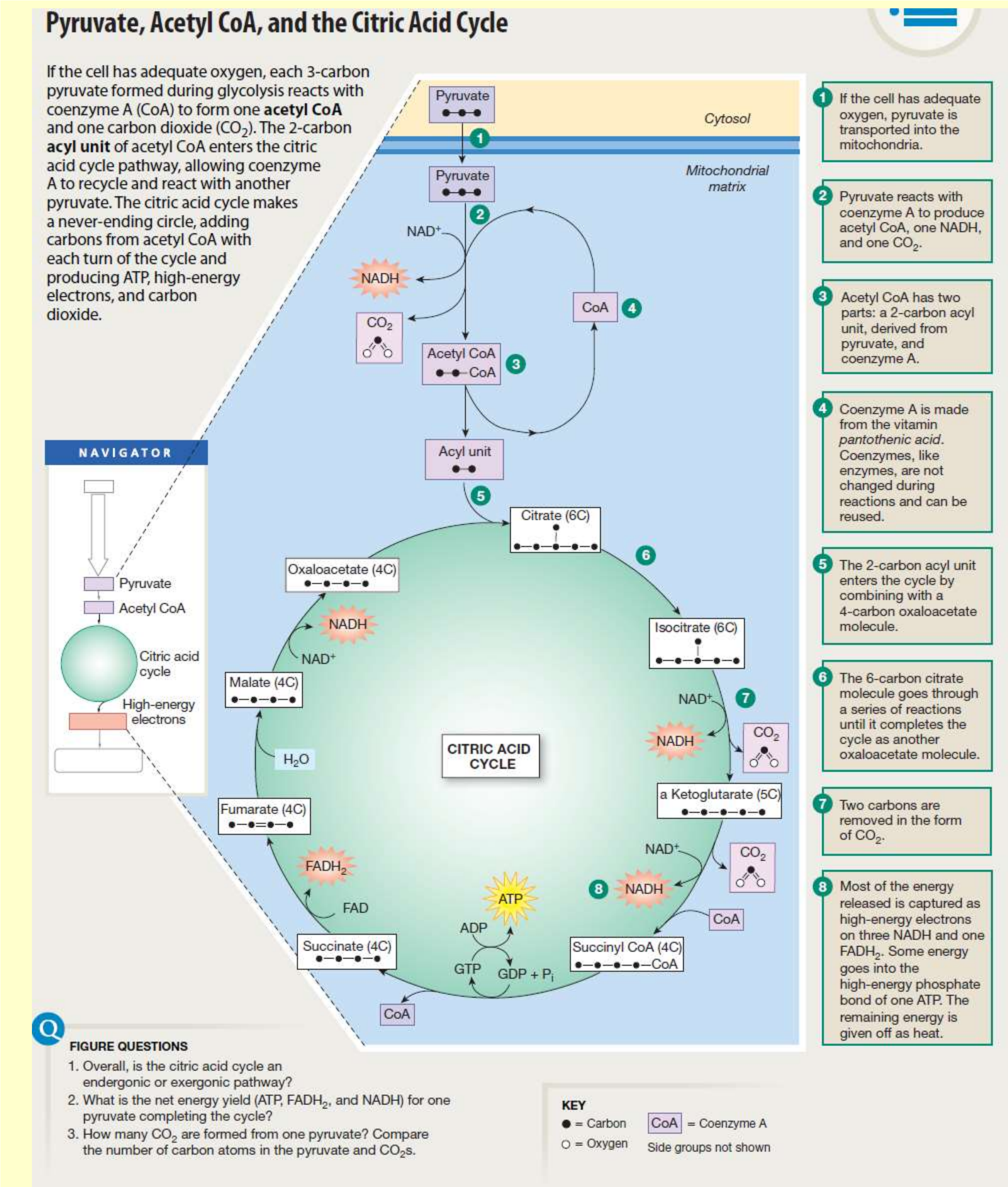
$$C_6H_{12}O_6 + 6\ O_2 \xrightarrow{30\text{-}32\ \text{ADP} + P_i \ \rightarrow\ 30\text{-}32\ \text{ATP}} 6\ CO_2 + 6\ H_2O$$





This icon represents the different steps in the metabolic summary figure. Look for it in the figures that follow to help you navigate your way through metabolism.

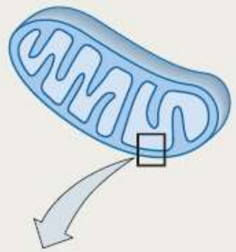
Silverthorn, D. U. Human Physiology – an Integrated Approach. 6th. edition. Pearson Education, Inc. 2012.

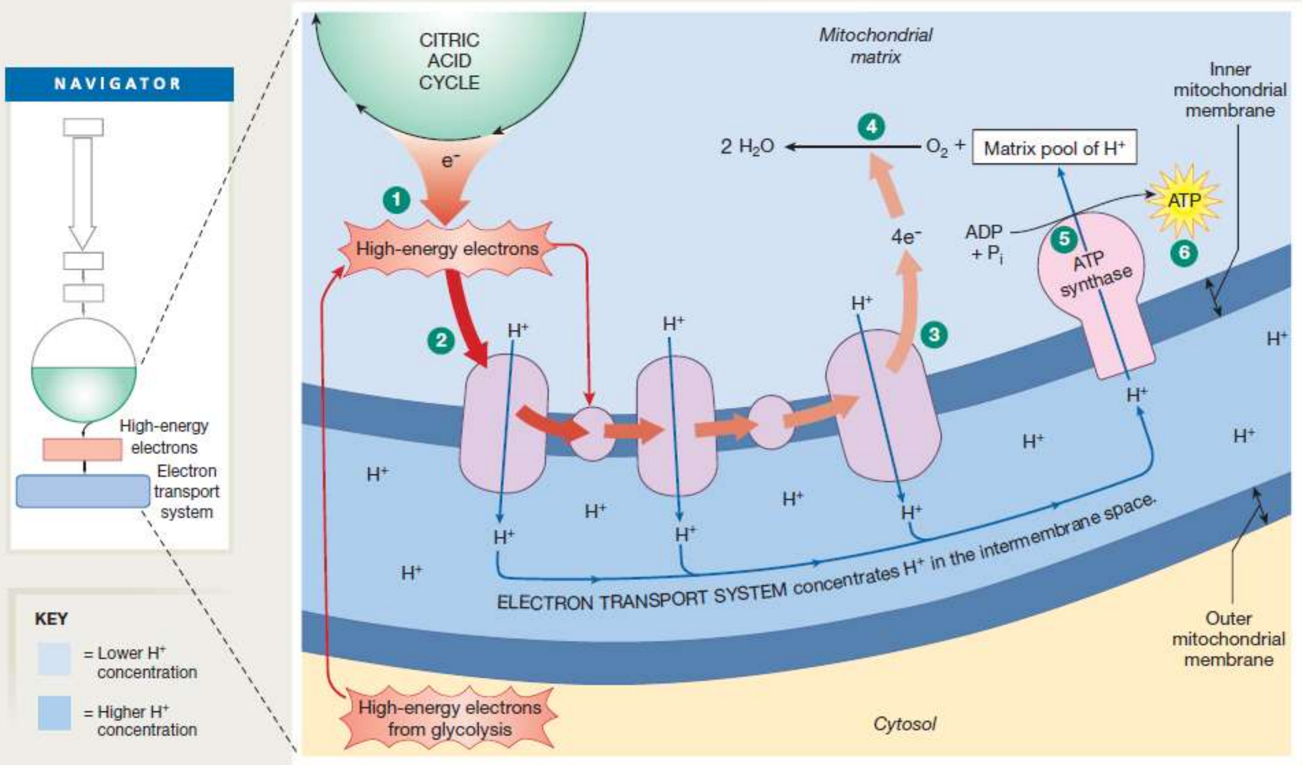


Silverthorn, D. U. Human Physiology – an Integrated Approach. 6th. edition. Pearson Education, Inc. 2012.

The Electron Transport System

The final step in aerobic ATP production is energy transfer from high-energy electrons of NADH and $FADH_2$ to ATP. This energy transfer requires mitochondrial proteins known as the **electron transport system (ETS)**, located in the inner mitochondrial membrane. ETS proteins include enzymes and iron-containing **cytochromes**. The synthesis of ATP using the ETS is called **oxidative phosphorylation** because the system requires oxygen to act as the final acceptor of electrons and H^+. The **chemiosmotic theory** says that potential energy stored by concentrating H^+ in the intermembrane space is used to make the high-energy bond of ATP.





1. NADH and $FADH_2$ release high-energy electrons and H^+ to the ETS. NAD^+ and FAD are coenzymes that recycle.
2. Energy released when pairs of high-energy electrons pass along the transport system is used to concentrate H^+ from the mitochondrial matrix in the intermembrane space. The H^+ concentration gradient is a source of potential energy.
3. By the end of the ETS, the electrons have given up their stored energy.
4. Each pair of electrons released by the ETS combines with two H^+ and an oxygen atom, creating a molecule of water, H_2O.
5. H^+ flow back into the matrix through a protein known as **ATP synthase**. As the H^+ move down their concentration gradient, the synthase transfers their kinetic energy to the high-energy phosphate bond of ATP. Because energy conversions are never completely efficient, a portion of the energy is released as heat.
6. Each three H^+ that shuttle through the ATP synthase make a maximum of one ATP.

Silverthorn, D. U. Human Physiology – an Integrated Approach. 6th. edition. Pearson Education, Inc. 2012.

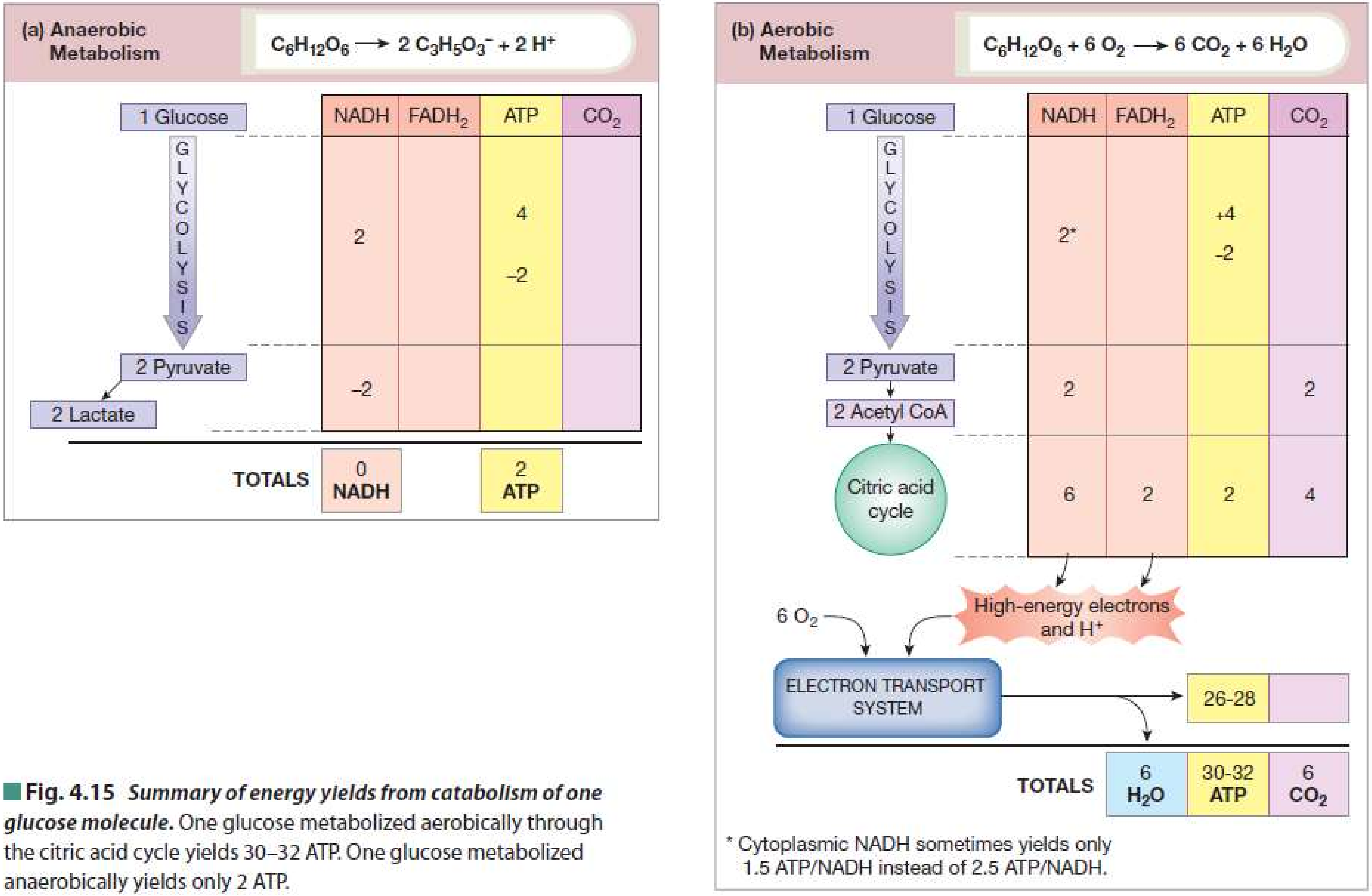


Fig. 4.15 ***Summary of energy yields from catabolism of one glucose molecule.*** One glucose metabolized aerobically through the citric acid cycle yields 30–32 ATP. One glucose metabolized anaerobically yields only 2 ATP.

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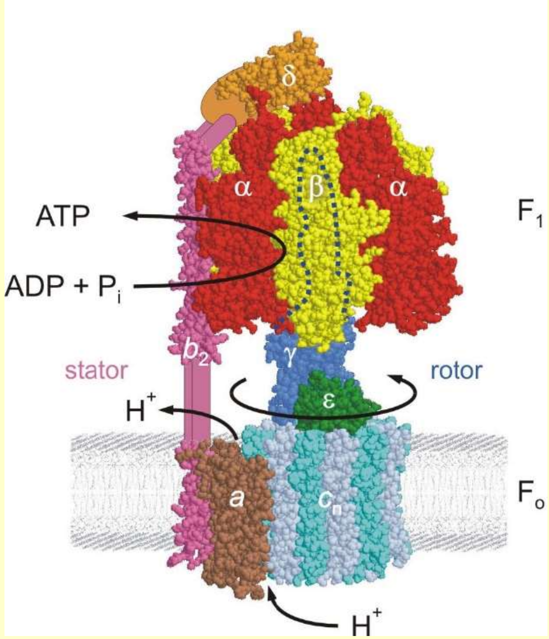
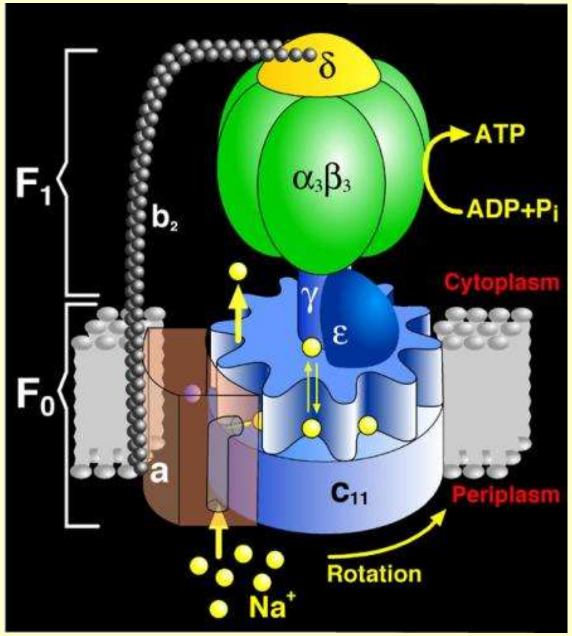
ATP synthase

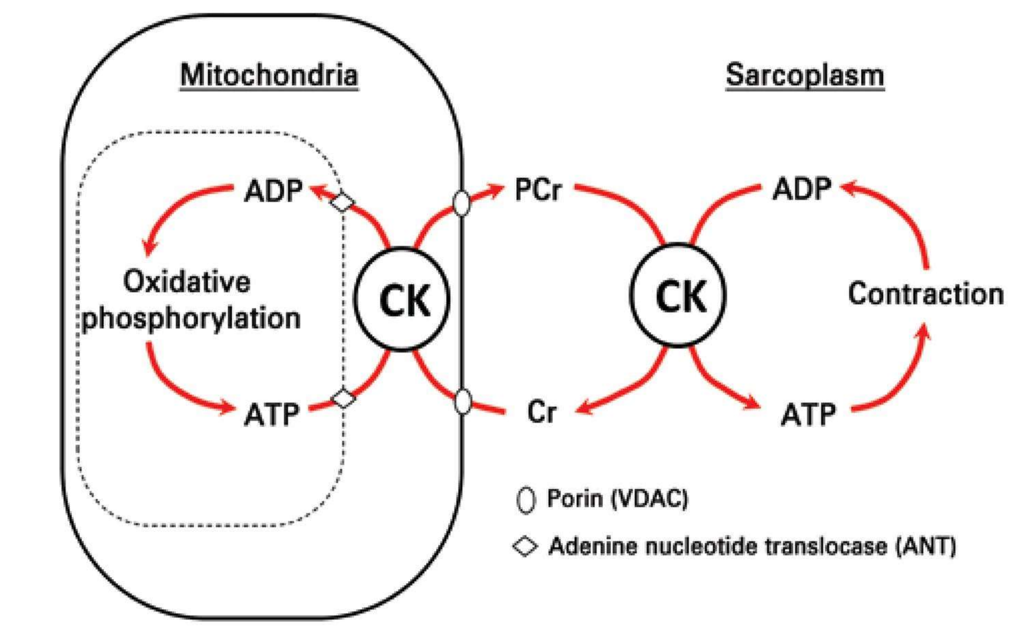
- Thylakoid membrane and the inner mitochondrial membrane
- F0 and F1 (matrix) „segments“
- F1 – 5 subunits
- F0 – 10 subunits





Phosphocreatine

- The most abundant macroergic (substance) compound
- 3 – 8x larger amounts compared to ATP
- 8500 cal/M and 13000 cal/M at 37°C and low concentrations of reactants (ATP 12000)
- dynamic process of energy transfer and mutual conversion of ADP-phosphocreatine / creatine-ATP
- „ATP-phosphocreatine system = maintenance of ATP amounts



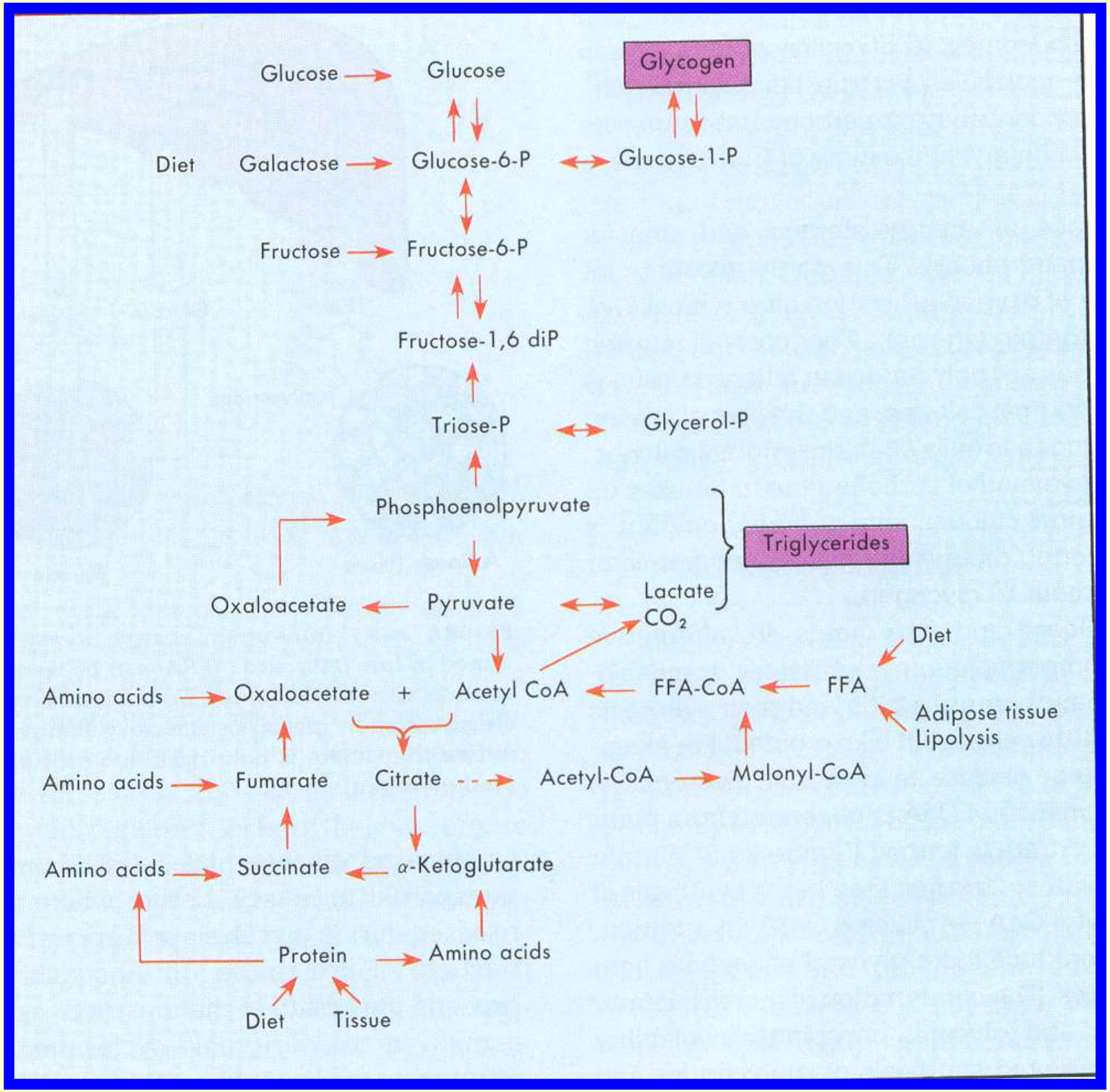
ADP: adenosine diphosphate; CK: creatinine kinase; PCr: phosphocreatine; ATP: adenosine triphosphate; Cr: free creatinine

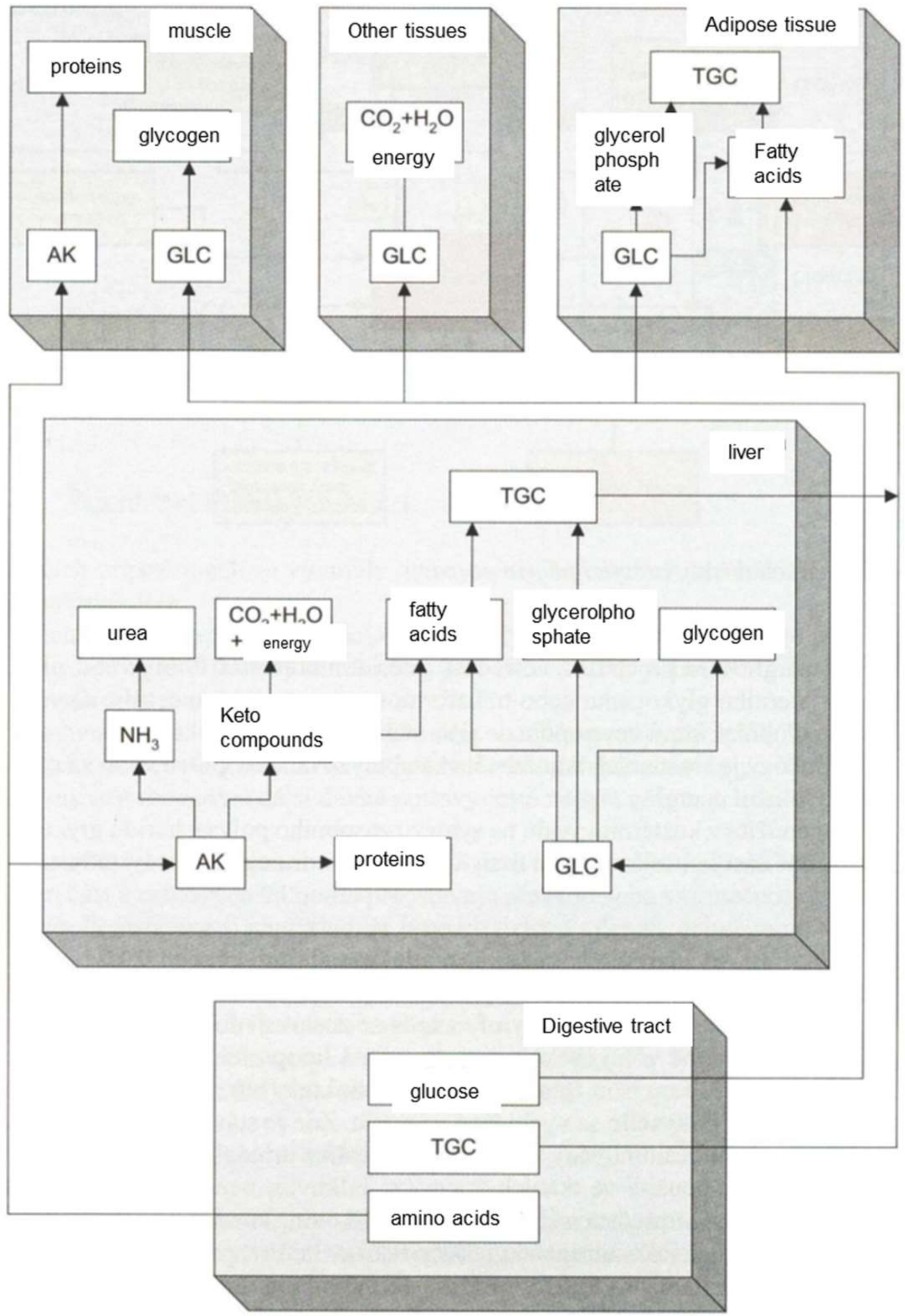
STORAGE AND TRANSPORT OF ENERGY

- Both input and otput of energy are irregular – necessity of storage
- **75%** of stores: triglycerides (9kcal/g) in adipose tissue (10-30% of body mass), lasts up to 2 months ; source – dietary FA and esterification with α-glycerolphosphate or synthesis from acetylCoA (from glycolysis) – saccharides are converted to more effective store of energy = lipids
- **25%** of stores: proteins (4kcal/g); conversion to saccharides (gluconeogenesis during stress); adverse effects on organism
- Less than **1%** of stores: saccharides (4kcal/g) as glycogen; important for CNS!!! and short-term enormous exercise; ¼ of glycogen stores in liver (75-100g), rest in muscles (300-400g); liver glycogen – glycogenolysis – release of glucose; muscle glycogen – used only in muscles (no glukoso-6-phosphatase)
- Gluconeogenesis: from pyruvate, lactate and glycerol and AA (except of leucin);NO from acetyl-CoA
- Storage and transport of energy requires input of other energy: 3% from original energy – lipids (triglycerides to adipose tissue), 7% - glucose (glycogen), 23% - conversion of saccharides to lipids, 23% - conversion of AA to proteins or glucose (glycogen).

GLUCOSE AND FA

- Alternative
- Reciprocal relationships between utilisation, synthesis and storage
- ABUNDANCE OF GLUCOSE – acceleration of glycolysis – more pyruvate, more citrate – citrate activates 1.step in synthesis of FA (acetyl CoA – malonyl CoA)
- Accelerated glycolysis – more glycerol phosphate; increased synthesis of FA and increased availability of glycerol phosphate = stimulation of synthesis of triglycerides and reduction of β-oxidation
- THUS: increased utilisation of saccharides shifts lipid metabolism from oxidation to storage
- OVERSUPPLY WITH FA – acceleration of β-oxidace; its intermediates slow down glycolysis and accelerate gluconeogenesis and glycogenogenesis
- THUS: increased utilisation of FA shifts saccharide metabolism from oxidation to storage
- Humoural regulation


Glucose
Glucose
Glycogen
Diet
Galactose
Glucose-6-P
Glucose-1-P
Fructose
Fructose-6-P
Fructose-1,6 diP
Triose-P
Glycerol-P
Phosphoenolpyruvate
Triglycerides
Oxaloacetate
Pyruvate
Lactate
CO_2
Diet
Amino acids
Oxaloacetate
+
Acetyl CoA
FFA-CoA
FFA
Adipose tissue
Lipolysis
Amino acids
Fumarate
Citrate
Acetyl-CoA
Malonyl-CoA
Amino acids
Succinate
α-Ketoglutarate
Protein
Amino acids
Diet
Tissue



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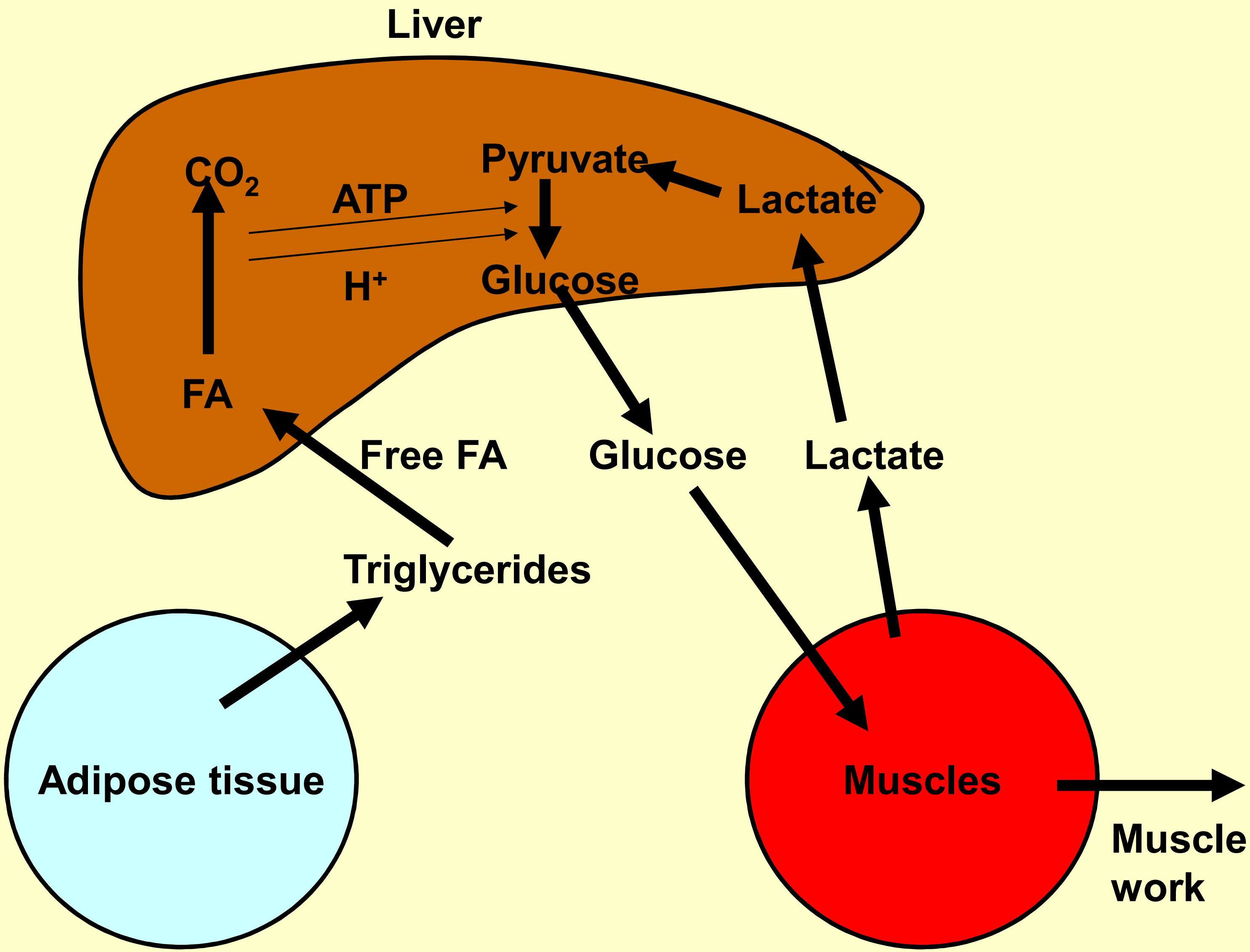
TRANSPORT OF ENERGY BETWEEN ORGANS



Muscle – source of energy and metabolism

- = conversion of energy into mechanic work
- Phosphocreatine – hydrolysis to creatine and phosphate
- At rest, some ATP in the mitochondria transfers its phosphate to creatine = phosphorylcreatine store is built up
- During exercise, the phosphorylcreatine is hydrolyzed at the junction between the myosin heads and actin, forming ATP from ADP and thus permitting contraction to continue
- At rest and during light exercise, muscles utilize lipids in the form of free fatty acids as their energy source
- As the intensity of exercise increases, lipids alone cannot supply energy fast enough and so use of carbohydrate becomes the predominant component in the muscle fuel mixture
- During exercise, much of the energy for phosphorylcreatine and ATP resynthesis comes from the breakdown of glucose to CO_2 and H_2O
- Glucose in the bloodstream enters cells, where it is degraded through a series of chemical reactions to pyruvate
- Another source of intracellular glucose, and consequently of pyruvate, is glycogen
- When adequate O_2 is present, pyruvate enters the citric acid cycle and is metabolized—through this cycle and the so-called respiratory enzyme pathway—to CO_2 and H_2O = AEROBIC GLYCOLYSIS, large quantities of ATP from ADP
- If O_2 supplies are insufficient, the pyruvate formed from glucose does not enter the tricarboxylic acid cycle but is reduced to lactate = ANAEROBIC GLYCOLYSIS - it does not require the presence of O_2
- After a period of exertion is over, extra O_2 is consumed to remove the excess lactate, replenish the ATP and phosphorylcreatine stores, and replace the small amounts of O_2 that were released by myoglobin - oxygen debt
- When muscle fibers are completely depleted of ATP and phosphorylcreatine, they develop a state of rigidity called rigor

TABLE 5–2 Classification of fiber types in skeletal muscles.

	Type 1	Type IIA	Type IIB
Other names	Slow, Oxidative (SO)	Fast, Oxidative, Glycolytic (FOG)	Fast, Glycolytic (FG)
Color	Red	Red	White
Myosin ATPase Activity	Slow	Fast	Fast
Ca^{2+}-pumping capacity of sarcoplasmic reticulum	Moderate	High	High
Diameter	Small	Large	Large
Glycolytic capacity	Moderate	High	High
Oxidative capacity	High	Moderate	Low
Associated Motor Unit Type	Slow (S)	Fast Resistant to Fatigue (FR)	Fast Fatigable (FF)
Membrane potential = –90 mV			
Oxidative capacity	High	Moderate	Low

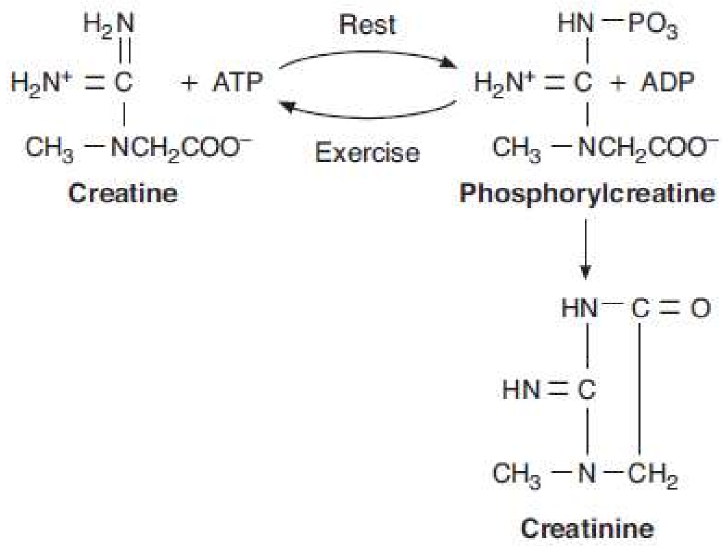


FIGURE 5–12 Creatine, phosphorylcreatine, and creatinine cycling in muscle. During periods of high activity, cycling of phosphorylcreatine allows for quick release of ATP to sustain muscle activity.

$$\text{ATP} + H_2O \rightarrow \text{ADP} + H_3PO_4 + 7.3\ \text{kcal}$$

$$\text{Phosphorylcreatine} + \text{ADP} \rightleftharpoons \text{Creatine} + \text{ATP}$$

$$\text{Glucose} + 2\ \text{ATP (or glycogen} + 1\ \text{ATP)} \xrightarrow{\text{Anaerobic}} 2\ \text{Lactic acid} + 4\ \text{ATP}$$

$$\text{Glucose} + 2\ \text{ATP (or glycogen} + 1\ \text{ATP)} \xrightarrow{\text{Oxygen}} 6\ CO_2 + 6\ H_2O + 40\ \text{ATP}$$

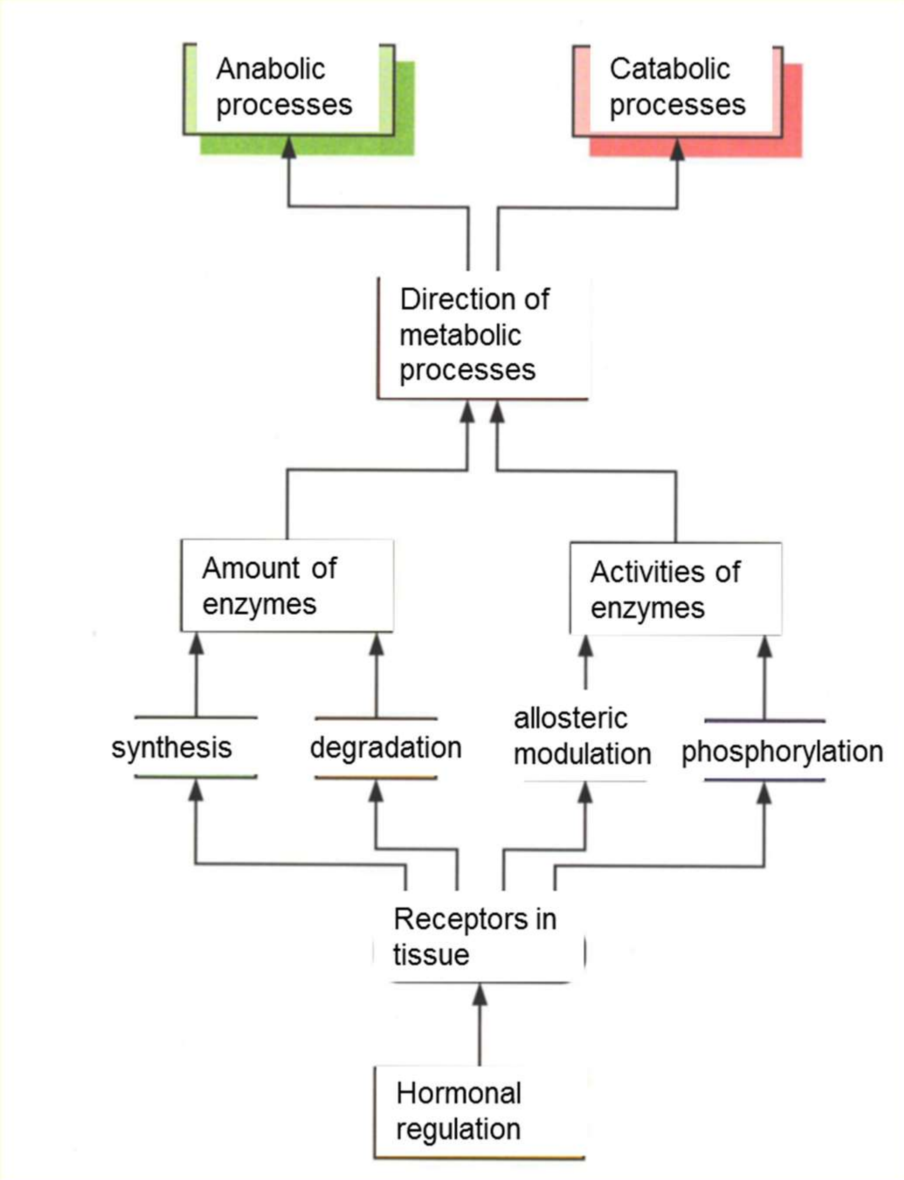
$$\text{FFA} \xrightarrow{\text{Oxygen}} CO_2 + H_2O + \text{ATP}$$

FIGURE 5–13 ATP turnover in muscle cells. Energy released by hydrolysis of 1 mol of ATP and reactions responsible for resynthesis of ATP. The amount of ATP formed per mole of free fatty acid (FFA) oxidized is large but varies with the size of the FFA. For example, complete oxidation of 1 mol of palmitic acid generates 140 mol of ATP.

Heat production in muscle

- Thermodynamically, the energy supplied to a muscle must equal its energy output
- The overall mechanical efficiency of skeletal muscle (work done/total energy expenditure) ranges up to 50% while lifting a weight during isotonic contraction and is essentially 0% during isometric contraction
- Considerable heat production
- **Resting heat**, the heat given off at rest, is the external manifestation of basal metabolic processes
- The heat produced in excess of resting heat during contraction is called the **initial heat**. This is made up of **activation heat**, the heat that muscle produces whenever it is contracting, and **shortening heat**, which is proportionate in amount to the distance the muscle shortens
- **Recovery heat** is the heat liberated by the metabolic processes that restore the muscle to its precontraction state.
- If a muscle that has contracted isotonically is restored to its previous length, extra heat in addition to recovery heat is produced = **relaxation heat**

Hormones and metabolism



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Hormones and metabolism of saccharides

- Insulin, IGF-I / II, glucagon, somatostatin, epinephrine, thyroid hormones, glucocorticoids, growth hormone

- Exercise
  - Entry of glucose into skeletal muscle is increased during exercise in the absence of insulin by causing an insulin-independent increase in the number of GLUT 4 transporters in muscle cell membranes
  - It persists for several hours after exercise, and regular exercise training can also produce prolonged increases in insulin sensitivity
  - Exercise can precipitate hypoglycemia in diabetics
  - Patients with diabetes should take in extra calories or reduce their insulin dosage when they exercise

- Catecholamines
  - Activation occurs via β-adrenergic receptors, which increase intracellular cAMP, and α-adrenergic receptors, which increase intracellular Ca^{2+}.
  - Hepatic glucose output is increased, producing hyperglycemia
  - In muscle, the phosphorylase is also activated via cAMP and presumably via Ca^{2+}, but the glucose 6-phosphate formed can be catabolized only to pyruvate because of the absence of glucose 6-phosphatase
  - Large amounts of pyruvate are converted to lactate, which diffuses from the muscle into the circulation
  - The lactate is oxidized in the liver to pyruvate and converted to glycogen
  - Lactate oxidation may be responsible for the calorigenic effect of epinephrine
- Thyroid hormones
  - The principal diabetogenic effect of thyroid hormones is to increase absorption of glucose from the intestine, but the hormones also cause (probably by potentiating the effects of catecholamines) some degree of hepatic glycogen depletion
  - Thyroid hormones may also accelerate the degradation of insulin
  - Calorigenic effect = increase of oxygen consumption almost in all tissues

- Adrenal glucocorticoids
  - Increased catabolism of proteins in tissues = increased amount of free AAs in blood plasma
  - Increased trapping of Aas in liver
  - Increased deamination and transamination of Aas
  - Increased conversion of oxalacetate to phosphopyruvate
  - Increased activity of liver fructose diphosphatase
  - Increased activity of liver glucose-6 phosphatase
  - Reduced utilization of glucose in peripheral tissues
  - Increased amounts of lactate and pyruvate in blood
  - Reduced lipogenesis in liver
  - Increased plasma levels of FFA
  - Increased production of keto compounds
  - Increased production of active glycogen synthase
- Growth hormone
  - Growth hormone mobilizes FFA from adipose tissue, thus favoring ketogenesis
  - It decreases glucose uptake into some tissues (“anti-insulin action”), increases hepatic glucose output, and may decrease tissue binding of insulin

RESPIRATORY QUOTIENT

$\boxed{\mathbf{RQ} = V_{CO2} : V_{O2}}$

(per unit of time, at steady state; related to 1 L of oxygen)

R – ratio of respiratory exchange (no steady state!)

Saccharides:	RQ = 1
Lipids:	RQ = 0,7
Proteins:	RQ = 0,8

- Saccharides (glucose)

$$\mathbf{C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_20}$$
$$\mathbf{RQ = 6/6 = 1{,}00}$$

- Fats (tripalmitin)

$$\mathbf{2\ C_{51}H_{96}O_6 + 145\ O_2 = 102\ CO_2 + 98\ H_2O}$$
$$\mathbf{RQ = 102/145 = 0{,}703\ (0{,}70)}$$

- At hyperventilation RQ increases (more CO_2).
- At intense exercise RQ 2.00 (more CO_2 + lactate is converted to CO_2)
- After the exercise RQ decreases down to 0.50
- At metabolic acidosis RQ increases.
- At metabolic alkalosis RQ decreases.

- **Metabolic rate / speed of metabolism**

1. **Physical work** (during recovery - compensation of oxygen debt).

2. Specific dynamic action (thermic effect, dietary induced thermogenesis) of food

= amount of energy expenditure above the resting metabolic rate due to the cost of processing food for use and storage

= energy required for digestion, absorption, and disposal of ingested nutrients

- A) The amount of **protein** that provides 100 kcal,

  increases metabolic rate for **30 kcal.**

- B) The amount of **saccharide** that provides 100 kcal,

  increases metabolic rate for **6 kcal**.

- C) The amount of **fats** that provides 100 kcal,

  increases metabolic rate for **4 kcal.**

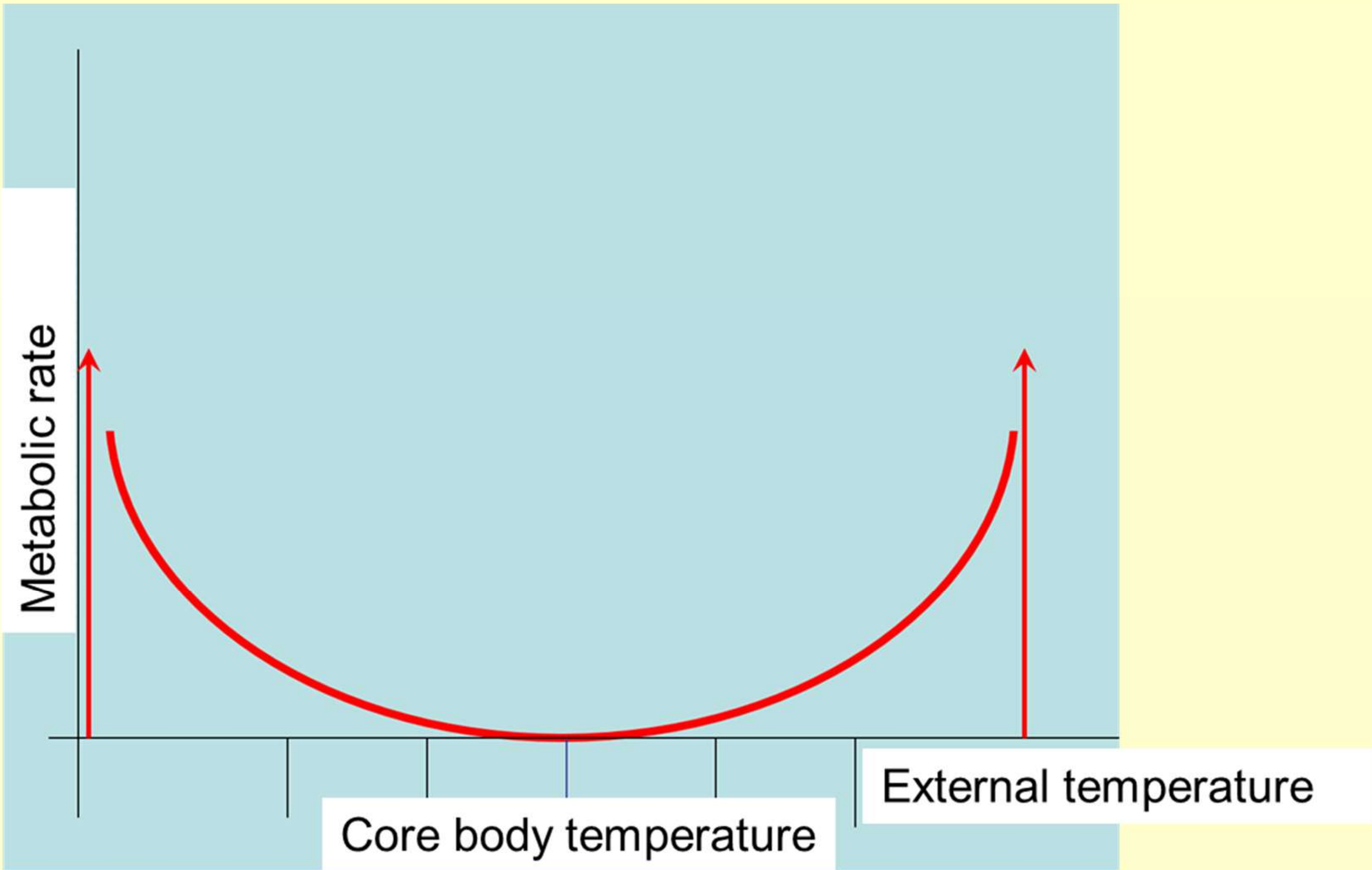
- The amount of energy of the nutrients is reduced by the specified amount of energy that was used to their assimilation.
  - **Proteins have the highest value of SDA ()**
  - instead of 100 kcal organism gets only 70 kcal.

- **3. External temperature –** U-shaped curve
- a) lower than body temperature -

  activation of mechanisms for heat retention (e.g. tremor)

  metabolic rate increases
- b) higher than body temperature -

  increasing temperature of body and increasing metabolic rate



4. Height, weight and body surface

5. Sex

- higher in men

6. Age

- decreases with aging

7. Emotion

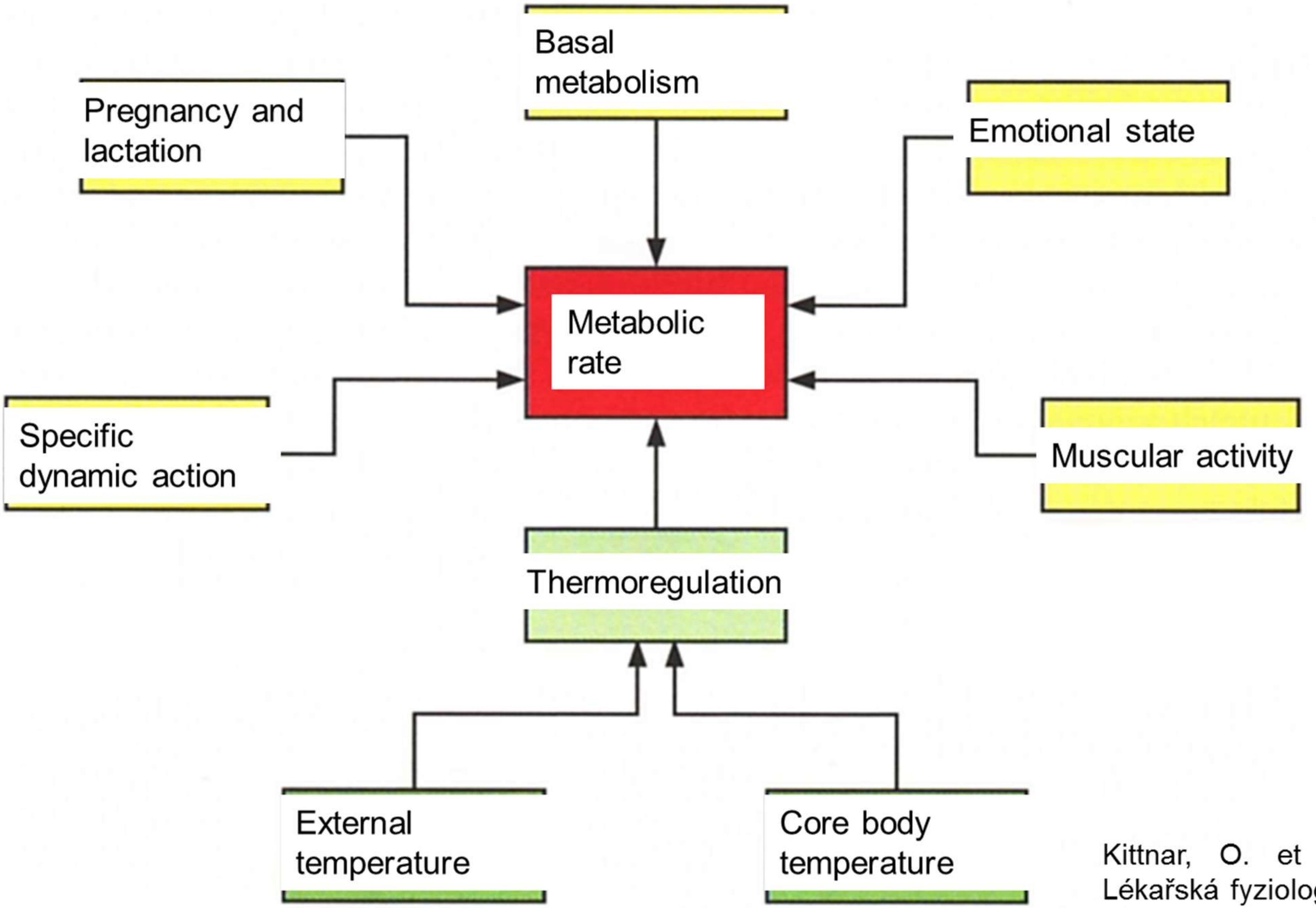
- excitement increases metabolism
- adrenalin increases muscle tension at rest, apathy and depression decrease metabolic rate

8. Body temperature

- increase for 1^{o} C = increase for 14%

9. Thyroid hormones (T4, T3)

10. Level of adrenaline and noradrenaline in the blood



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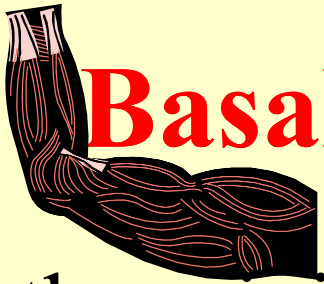
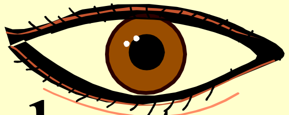
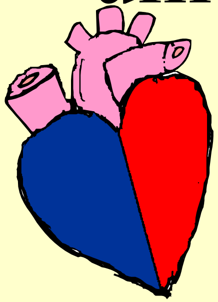
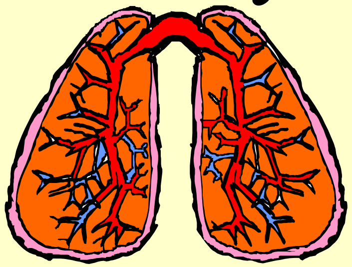


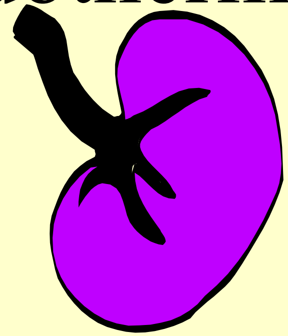
Basal metabolic rate (BMR)

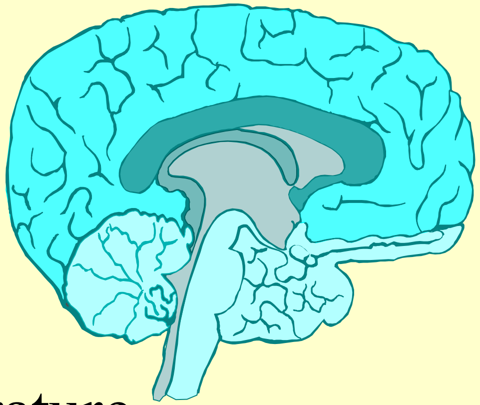


is the minimal rate of energy expenditure per unit time by endothermic animals at rest









- Lying down, calm, neutral external temperature
- 12-14 hours after meals, absence of strenuous physical work for 24 h
- Elimination of all the negative physical and psychological factors if possible

Basal metabolic rate (BMR)

- **In humans, it correlates with the body surface -** heat exchange occurs on the body surface
- What is the relationship between weight, height and body surface?

$$S = 0{,}007184 \,.\, W^{0{,}425} \,.\, H^{0{,}725}$$

S = body surface - m^2

W = weight - kg

H = height - cm

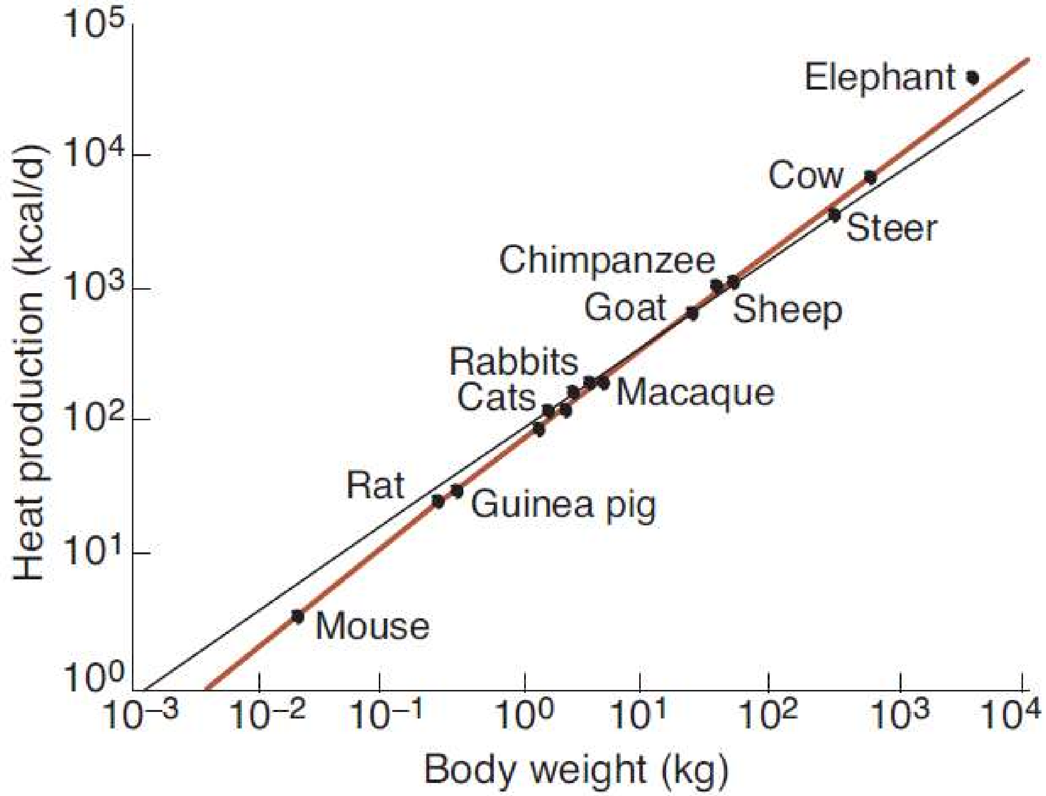


FIGURE 27–9 Correlation between metabolic rate and body weight, plotted on logarithmic scales. The slope of the colored line is 0.75. The black line represents the way surface area increases with weight for geometrically similar shapes and has a slope of 0.67. (Modified from Kleiber M and reproduced with permission from McMahon TA: Size and shape in biology. Science 1973;179:1201. Copyright © 1973 by the American Association for the Advancement of Science.)

Basal metabolic rate (BMR)

Adult male about 40 kcal/m^2/h

(= about 2000 kcal / 24 h)

Women - lower

Older - lower

(kg) (cm) (years)

BMR men = 66 + (13,7 . weight) + (5,0 . height) - (6,8 . age)

BMR women = 655 + (9,6 . weight) + (1,85 . height) - (4,7 . age)

Harris-Benedict Equation (1919)

Basal metabolic rate (BMR)
Effect of sex

BMR men = 66 + (13,7 . weight) + (5,0 . height) - (6,8 . age)

BMR women = 655 + (9,6 . weight) + (1,85 . height) - (4,7 . age)

Man 20 years, 80 kg, 185 cm
BMR = 1950 kcal

Woman 20 years, 55 kg, 165 cm
BMR = 1395 kcal

Basal metabolic rate (BMR)
Effect of sex

BMR men = 66 + (13,7 . weight) + (5,0 . height) - (6,8 . age)

BMR women = 655 + (9,6 . weight) + (1,85 . height) - (4,7 . age)

Man 20 years, 80 kg, 185 cm
BMR = 1950 kcal

Woman 20 years, 80 kg, 185 cm
BMR = 1730 kcal

Difference of about 10%

Basal metabolic rate (BMR)
Effect of age

BMR men = 66 + (13,7 . weight) + (5,0 . height) - (6,8 . age)

BMR women = 655 + (9,6 . weight) + (1,85 . height) - (4,7 . age)

Man 20 years, 75 kg, 180 cm
BMR = 1860 kcal

Man 70 years, 75 kg, 180 cm
BMR = 1520 kcal

Difference of about 20%

Basal metabolic rate (BMR)
Effect of age

BMR men = 66 + (13,7 . weight) + (5,0 . height) - (6,8 . age)

BMR women = 655 + (9,6 . weight) + (1,85 . height) - (4,7 . age)

Woman 20 years, 60 kg, 165 cm
BMR = 1440 kcal

Woman 70 years, 60 kg, 165 cm
BMR = 1200 kcal

Difference of about 15%

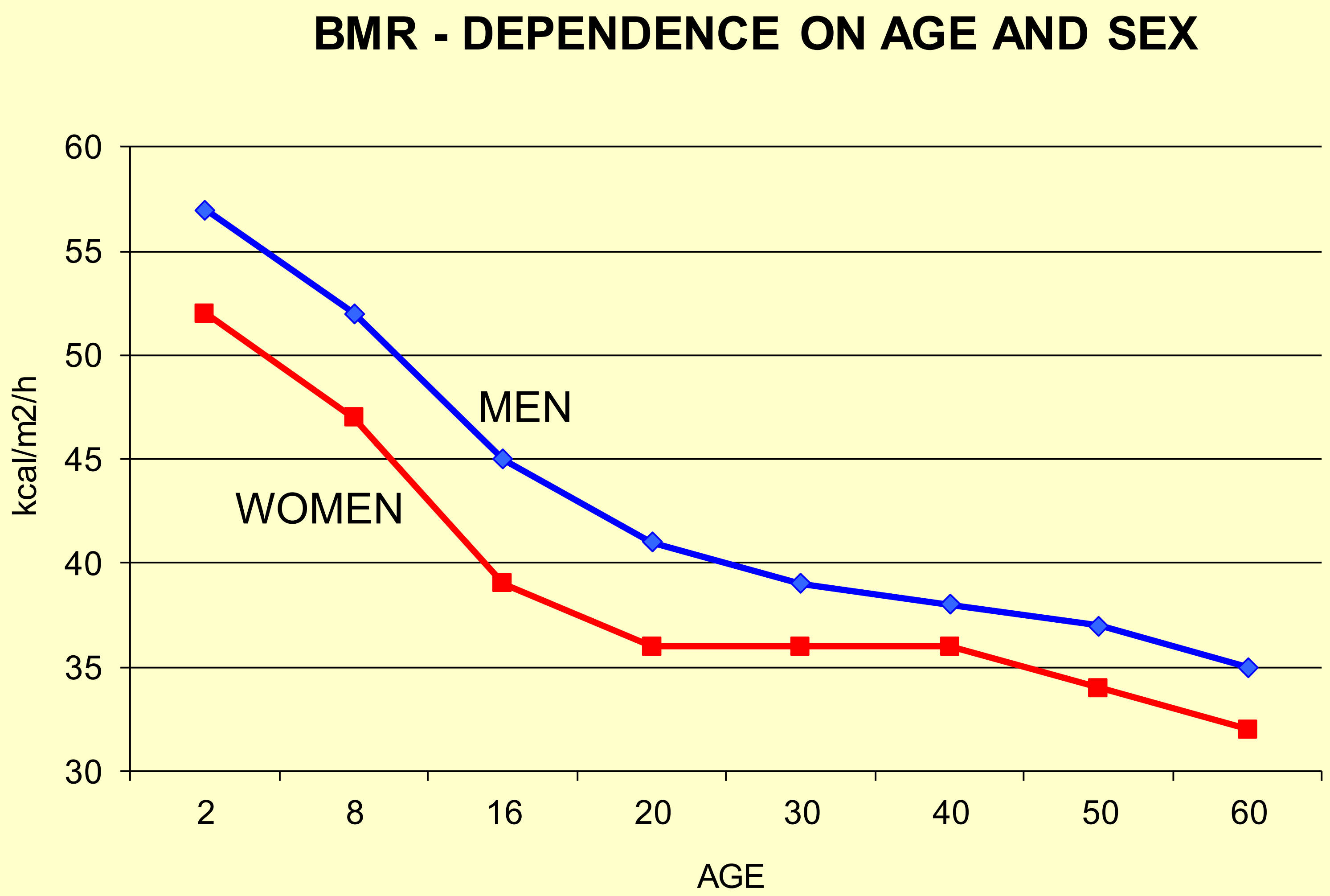
Basal metabolic rate (BMR)
Effect of age

BMR men = 66 + (13,7 . weight) + (5,0 . height) - (6,8 . age)

BMR women = 655 + (9,6 . weight) + (1,85 . height) - (4,7 . age)

For women BMR practically unchanged between 20 and 40 years, in men still slowly decreasing (2-3% annually).

The decrease in BMR in women between 40 and 50 years is steeper than in men.


BMR - DEPENDENCE ON AGE AND SEX
60
55
50
45
40
35
30
kcal/m2/h
MEN
WOMEN
2
8
16
20
30
40
50
60
AGE

Basal metabolic rate (BMR) Effect of age

The largest decrease of BMR
occurs in puberty

The lowest decrease of BMR in men
is between 30 and 50 years,
In women between 20 and 40 years

During menopause, BMR decreases more sharply
than in the same age for men

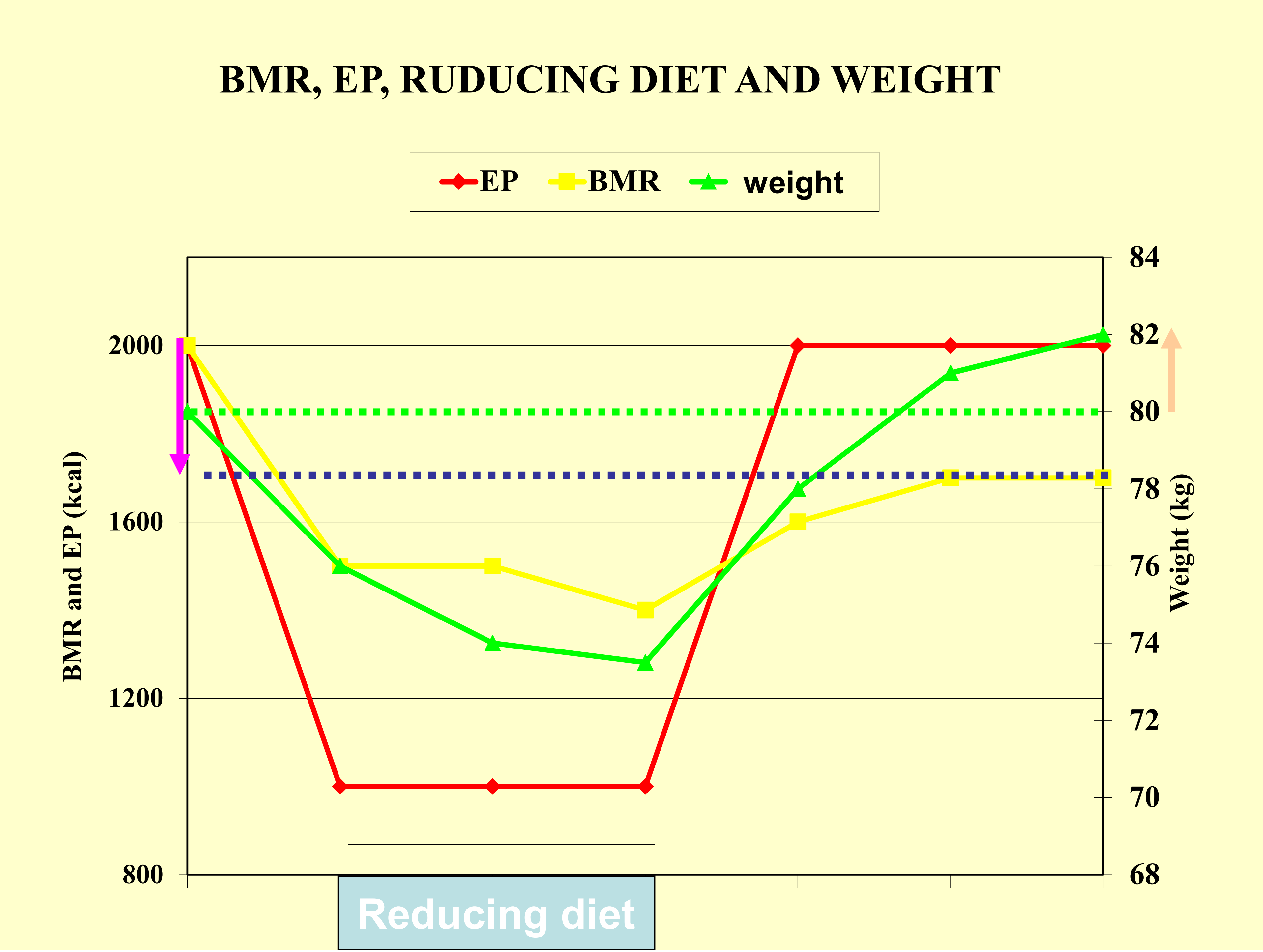
Basal metabolic rate (BMR)

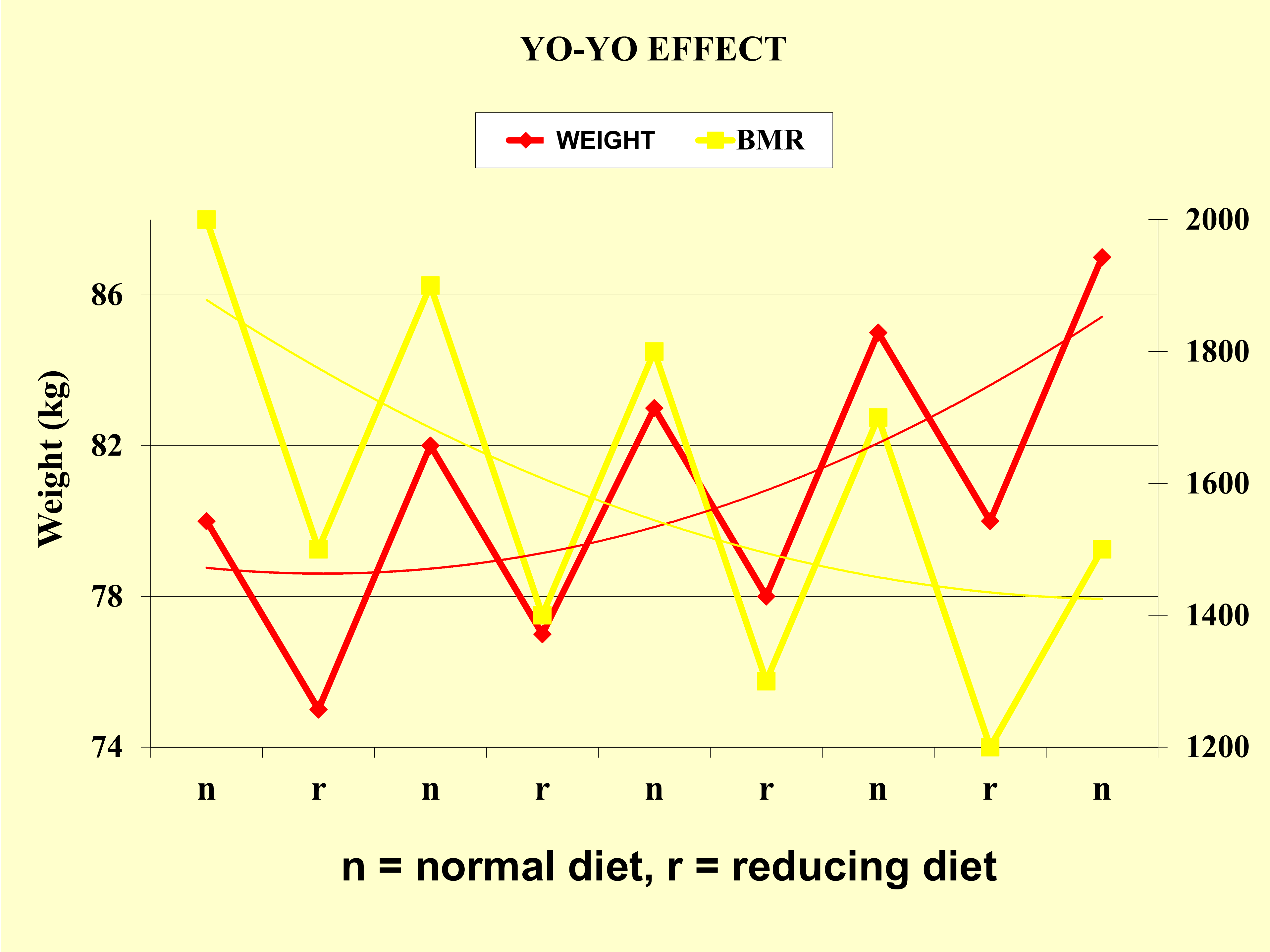
Long-term starvation = a decrease BMR

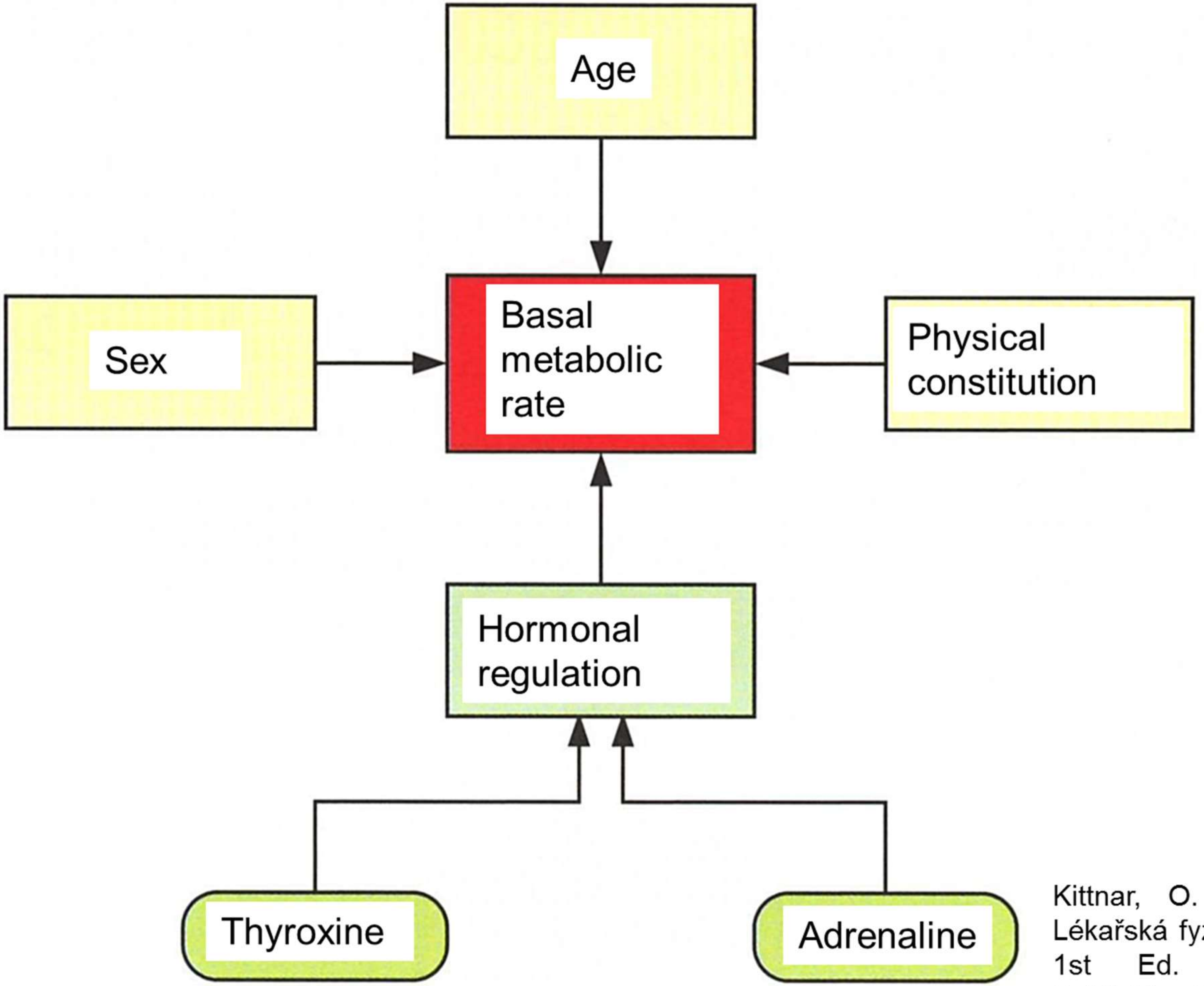
- sympathetic activity decreases
- amount of catecholamines decreases
- production of thyroid hormones decreases

In reducing diet the initial sharp decline of body weight is followed by its slowing

After food intake sympathetic activity increases and BMR increases too


BMR, EP, RUDUCING DIET AND WEIGHT
EP
BMR
weight
BMR and EP (kcal)
800
1200
1600
2000
Weight (kg)
68
70
72
74
76
78
80
82
84
Reducing diet


YO-YO EFFECT
WEIGHT
BMR
Weight (kg)
86
82
78
74
2000
1800
1600
1400
1200
n
r
n
r
n
r
n
r
n
n = normal diet, r = reducing diet



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Factors that influence basal metabolic rate

- Muscular work (both before and at measurements)
- Food intake (before measurement)
- High or low ambient temperature (curve is U-shaped)
- Height, weight, body surface
- Sex
    - Testosterone - increase by 10 to 15%
    - Female sex hormones insignificantly
- Age
- Emotional status
- Body temperature
- Thyroid status
    - Secretion of maximal amount of thyroxine = increase by 50 – 100 %
    - Adaptation of thyroid gland on different climatic conditions (increased secretion in cold areas, and lowered secretion in warm climates) = differences in BMR
    - In the polar regions BMR is increased by 10-20%
- Growth hormone
    - Increase in BMR (stimulation of cell metabolism, increase muscle mass)
    - Substitution therapy = 20% increase
- Amount of catecholamines in blood
- Sleep - reduction by 10 - 15% = reduction in muscle tone + decreased activity of the nervous system
- Malnutrition - prolonged malnutrition decreases BMR by up to 30%

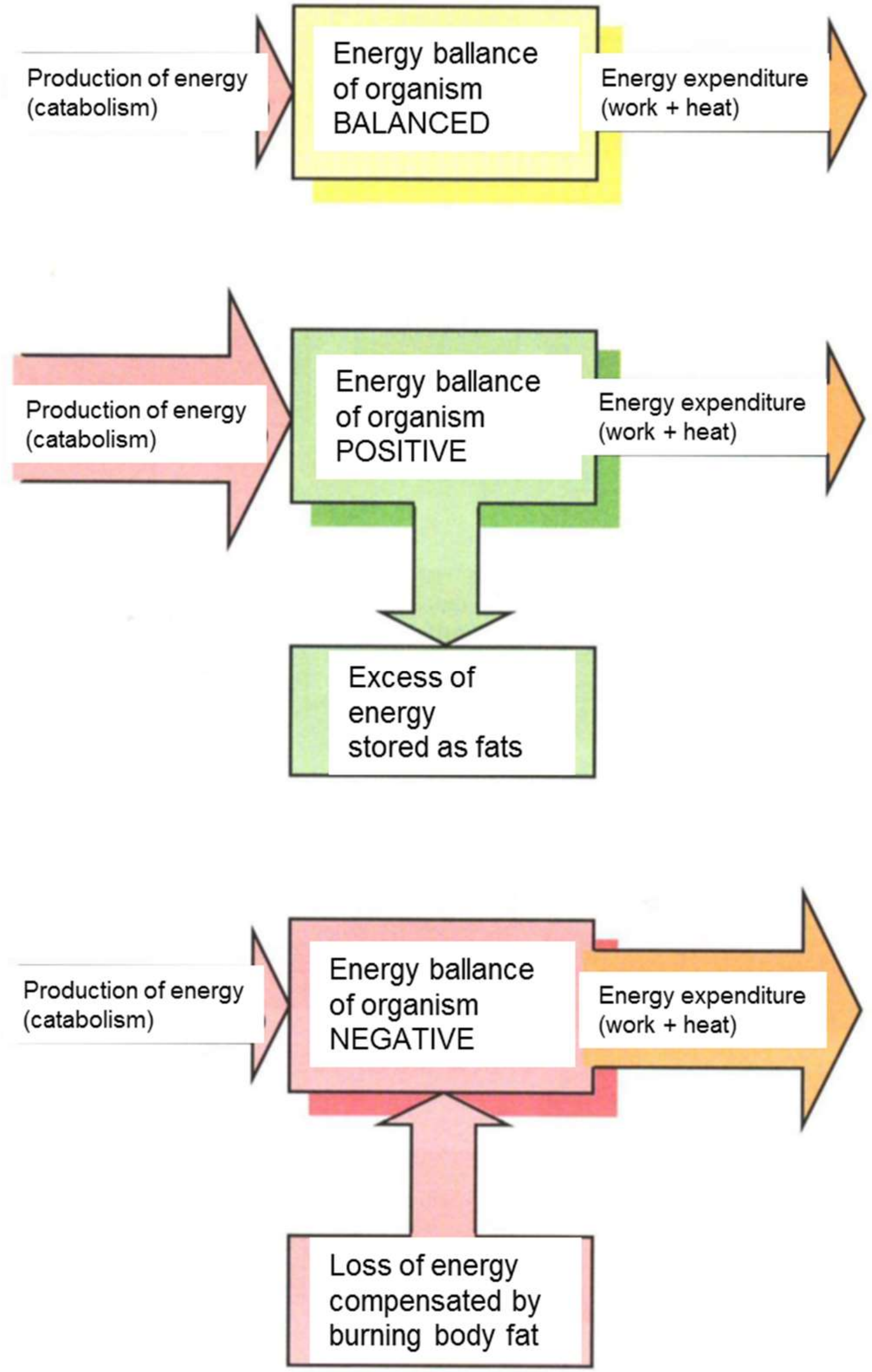
Energy balance

- The balance between energy intake and expenditure
- Negative energy balance = internal stores are consumed (catabolism of glycogen, proteins, and fats)

= **loss of weight**

- Positive energy balance = intake of energy predominates over energy consumption

= **gaining weight**



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Energy balance

With the exception of humans

and some domesticated and hibernating animals appetite regulates food intake

Obesity is a rarity

Over 70% of the human population is overweight or obese

Energy expenditure

Energetic equivalent (EE)

Amount of energy (Q)

released during consumption of 1 liter of oxygen

(Q/VO_2)

Energy expenditure

Energetic equivalent (EE)

- **saccharides** 21,1 kJ = 5,05 kcal
- **proteins** 18,0 kJ = 4,31 kcal
- **fats** 19,0 kJ = 4,55 kcal

incomplete catabolism
(human organism is not able to
use the energy of the nitrogen compounds)

Energy expenditure

Energetic equivalent (EE)

Mixed diet
(60% carbohydrate, 30% fat, 10% protein)

EE = 20,1 kJ = 4,81 kcal

4,8 kcal

Energy expenditure

At rest, human consumes about 3,4 - 3,6 ml O_2/kg/min

1 MET (metabolic equivalent)

The Metabolic Equivalent of Task (MET), or simply metabolic equivalent, is a physiological measure expressing the energy cost of physical activities and is defined as the ratio of metabolic rate (and therefore the rate of energy consumption) during a specific physical activity to a reference metabolic rate, set by convention to 3.5 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$ or equivalently.

1 MET is also defined as 58.2 W/m^2 (18.4 Btu/h·ft^2), which is equal to the rate of energy produced per unit surface area of an average person seated at rest. The surface area of an average person is 1.8 m^2 (19 ft^2). Metabolic rate is usually expressed in terms of unit area of the total body surface

What energy is it??

VO_2 (women) = 3,4 . 4,8 =16,3 cal/kg/min

(lower by 5 - 15%)

VO_2 (men) = 3,6 . 4,8 =17,3 cal/kg/min

Energy expenditure

1 MET

the amount of oxygen that human consumes at rest

for 1 min/1 kg of weight

About 3,5 ml/kg/min

Energy expenditure

Man 20 years, 75 kg, 180 cm
BMR = 1860 kcal (24 hod)

Calculation based on MET:

- **17 cal/kg/min**
- **1275 cal/min**
- **76500 cal/h = 76,5 kcal/h**
- **1836 kcal/24 h**

Values are approximately the same

	MET	VO2 (l/min)	TF (/min)
Light (easy)	< 3,0	< 0,5	< 90
Medium	3,0 – 4,5	0,5 – 1,0	90 – 110
Heavy	4,6 – 7,0	1,0 – 1,5	110 – 130
Very heavy	7,1 – 10,0	1,5 – 2,0	130 – 150
Exhausting	> 10	> 2,0	> 150

Limits of this evaluation:

- **Working capacity is not considered**

At the maximum working capacity of 10 METs will work at 5 METs draw a capacity from 50% (medium)

At the maximum working capacity of 5 METs will work at 5 METs maximum work (exhaustive)

Limits of this evaluation:

- **Working capacity is not considered**
- **maximal aerobic capacity is not considered**

At VO_2/kg max = 50 ml/kg/min the work at 25 ml ml/kg/min draw the capacity from 50% (medium).

At VO_2/kg max = 30 ml/kg/min the work at 25 ml/kg/min will draw the capacity from 83% (very heavy - exhaustive)

Limits of this evaluation:

- **Working capacity is not considered**
- **Maximal aerobic capacity is not considered**
- **Maximum pulse reserve is not considered**

Maximum pulse reserve (MTR) = TF max - TF rest

At TF max = 200 and TF rest = 70
Work at TF = 120 will draw MTR from 38%
(120 - 70 / MTR) (light)

At TF max = 150 and TF rest = 70
Work at TF = 120 will draw MTR from 63%
(120 - 70 / MTR) (heavy)

Energy expenditure values of some activities

Light (easy) work

• driver	1,5
• laborant	2,1
• barman	2,7
• car mechanic	2,7
• serviceman	2,8

Energy expenditure values of some activities

Medium work

• electrician	3,4
• nurse	3,4
• bricklayer	4,0
• room painter	4,1
• work with a chainsaw	4,4

Energy expenditure values of some activities

Heavy work	METs
• factory worker	5,4
• traditional agriculture	5,9
• coal miner	6,2
• digger	6,2
• porter of heavy loads	6,2

Energy expenditure values of some activities

Very heavy work	METs
• furnace operation	7,4
• hand saw cutting	7,8
• felling of trees	8,9
• slag operation	10,1

Exhausting work

Energy expenditure values of free time activities

	METs
• sweeping, cooking, washing dishes	2,9
• window cleaning, polishing floors, shopping	3,7
• beating carpets, furniture polishing	4,5

Energy expenditure values of free time activities

	METs
• playing cards, listening music	1,5
• energetic playing musical instruments	2,7
• playing billiards	2,5
• free ballroom dancing	4,1
• folk and modern dances	6,5
• very energetic dances	11,3

Energy expenditure values of free time activities

	METs
• garthering of forest fruits (berries)	2,5
• raking leaves	3,9
• spading, hoeing	5,0
• throwing with a shovel 5 kg/10x per min	6,6
• splitting wood	6,7
• Fishing in flowing water	3,9
• fishing in the stream	5,5

Energy expenditure values for sports

	METs
• Walking - speed of 5 km/h on the flat	4,1
• Walking - speed of 5 km/h uphill	8,0
• Running - speed of 8 km/h on the flat	7,3
• Marathon racing	18,4
• Cycling - 21 km/h	8,2
• Swimming - speed of 1.2 km / h (untrained)	7,1
• Competitive swimming	15,5

Energy expenditure values for sports

	METs
• Football	10,0
• recreational tennis doubles	5,5
• Recreational tennis single format	8,6
• Racing tennis single format	11,0
• Ski tourism	6,5
• Racing cross-country skiing	19,7
• Lightweight ski descent	7,7
• Alpine skiing	14,0

Energy expenditure values for sports

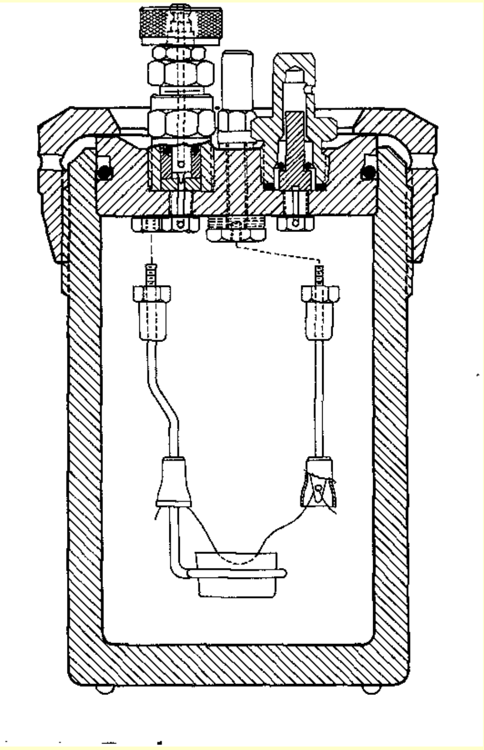
	METs
• Aerobics	5,6
• Ice hockey	25,7
• Racing rowing	23,4
• Golf	3,1
• Weight-lifting	14,4
• mountaineering	7,4

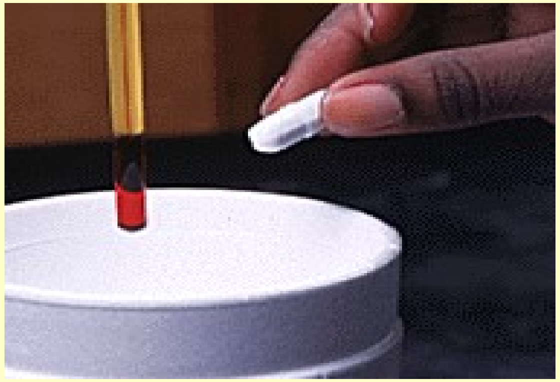
DIRECT CALORIMETRY

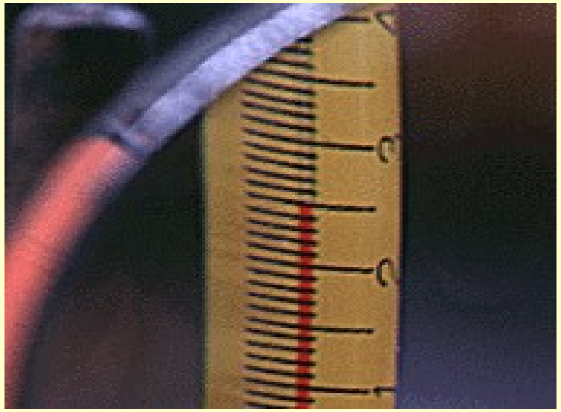
= measurement of energy released by burning of diet out of body (oxidation of compounds in a **calorimeter**)

- Adiabatic calorimeter = the content of calorimeter is heated
- Isothermal calorimeter = heat produced is conducted away

1. Caloric bomb
2. Whole-body calorimeter (for laboratory animals, for humans)



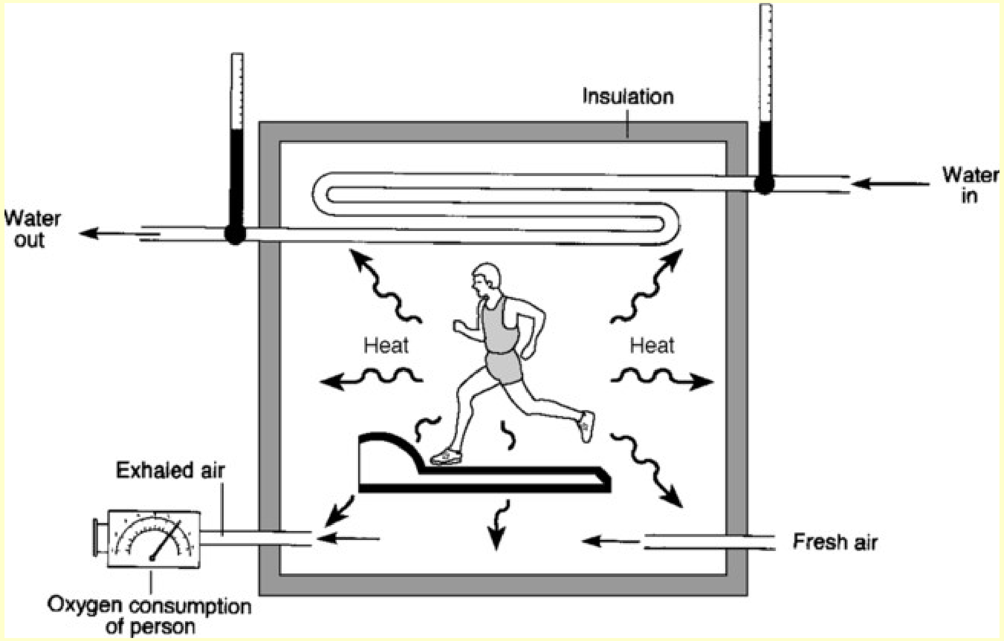


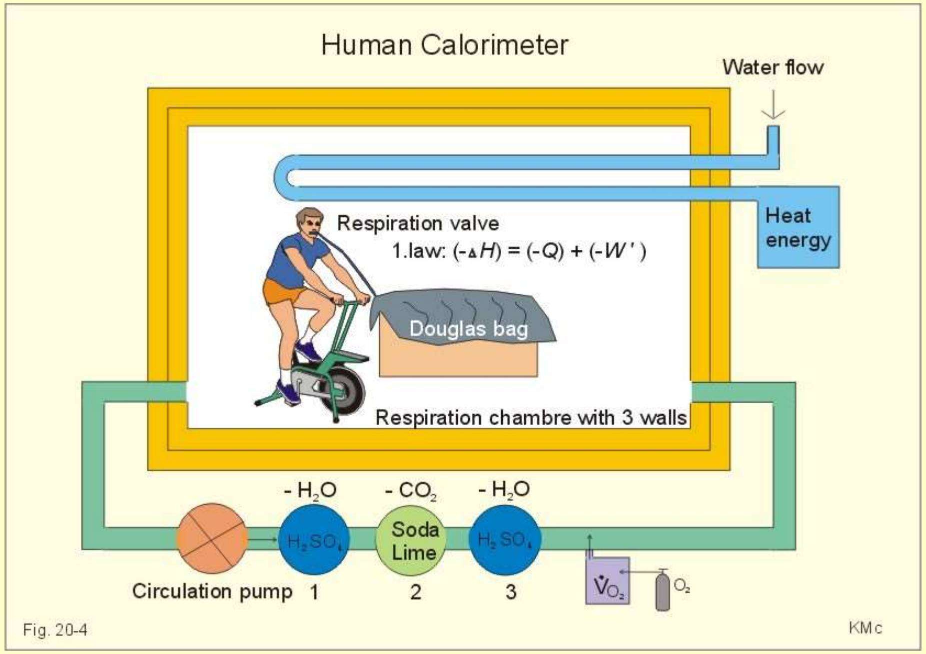


INDIRECT CALORIMETRY

PRACTICALS

- Amount of consumed O_2.
- Amount of energy released for 1 mol of consumed O_2 differs according to type of oxidated compound (the effect of diet composition)
- Open/closed systems
  - person inhales atmospheric air and exhales it into the analyzer
  - person inhales oxygen from the reservoir = closed system


Insulation
Water in
Water out
Heat
Heat
Exhaled air
Fresh air
Oxygen consumption of person


Human Calorimeter
Water flow
Heat energy
Respiration valve
1.law: $(-\Delta H) = (-Q) + (-W')$
Douglas bag
Respiration chambre with 3 walls
$-H_2O$
$-CO_2$
$-H_2O$
H_2SO_4
Soda Lime
H_2SO_4
$\dot{V}_{O_2}$
O_2
Circulation pump 1
2
3
Fig. 20-4
KMc

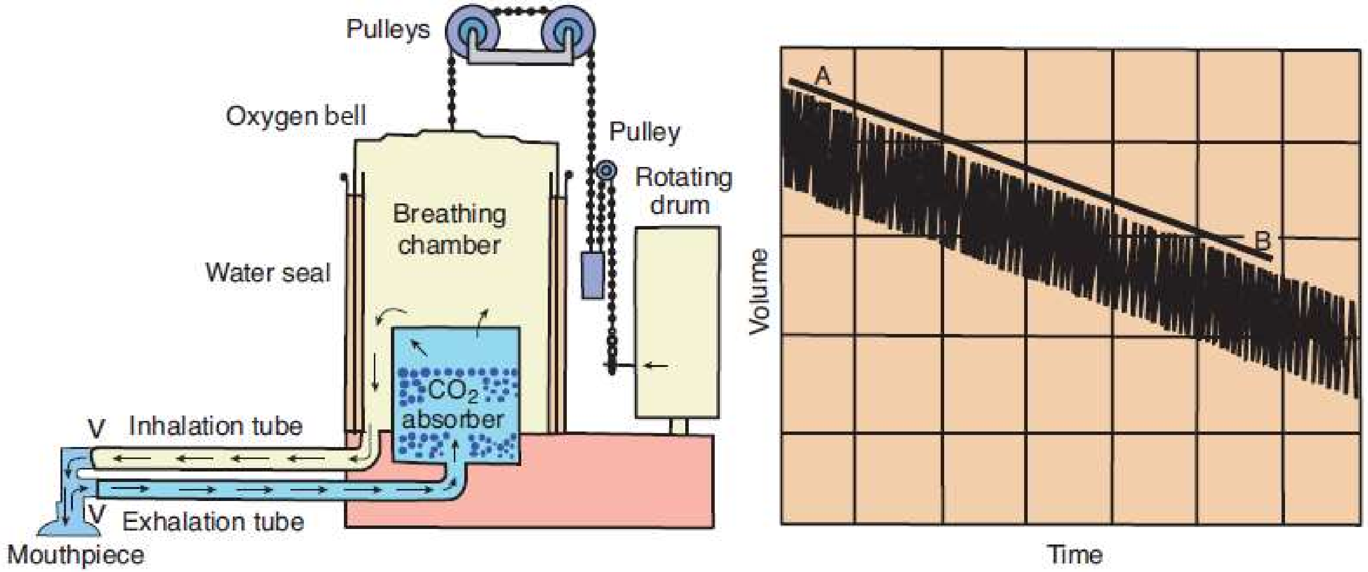


FIGURE 27–8 Diagram of a modified Benedict apparatus, a recording spirometer used for measuring human O_2 consumption, and the record obtained with it. The slope of the line AB is proportionate to the O_2 consumption. V: one-way check valve.

Barret, K.E., Boitano, S., Barman, S.M., Brooks, H.L. Ganong´s Review of Medical Physiology. 23rd Ed. McGraw-Hill Companies 2010