Nutrition

for Sport and Exercise, Third Edition

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3 Energy Systems and Exercise

Formulas for Resting Metabolic Rate

- **Harris Benedict (RMR)**
  - M: 66.5 + 13.8 x weight (kg) + 5 height (cm) – 6.8 x age (y)
  - F: 664 + 9.6 x weight (kg) + 1.8 height (cm) – 4.7 age (y)
- **Mifflin (RMR)**
  - M: 10 x weight (kg) + 6.25 x height (cm) - 5 x age (y) + 5
  - F: 10 x weight (kg) + 6.25 x height (cm) - 5 x age (y) – 161
- **Cunningham (RMR)**
  - 500 + (22 x FFM)

Total Daily Energy Expenditure

TDEEx = TDEE + TEF

TDEE= REE + NEAT + ExEE

REE (Resting Energy Expenditure) = 22 x FFM

NEAT (Non Exercise Activity Thermogenesis) = REE x Activity Factor (.3 light, .5 moderate, .7 heavy)

ExEE = time x METs (or calories expended per min based on weight)

TEF = TDEE x .06 to .10 (6-10%)

Model of Human Metabolism

$$\rho_C \frac{dG}{dt} = CI - DNL + GNG_P + GNG_F - G3P - CarbOx$$

$$\rho_F \frac{dF}{dt} = 3M_{FFA} FI / M_{TG} + \varepsilon_d DNL - KU_{excr} - (1-\varepsilon_k) KTG - FatOx$$

$$\rho_P \frac{dP}{dt} = PI - GNG_P - ProtOx$$

$$\begin{aligned} FFM &= BM + ECF + ECP + LCM \\ &= BM + ECF + ECP + ICW + P + G + ICS \\ &= BM + ECF + ECP + \hat{ICW} + P(1+h_P) + G(1+h_G) + ICS \end{aligned}$$

$$\frac{dECF}{dt} = \frac{1}{[Na]}\left(\Delta Na_{diet} - \xi_{Na}(ECF - ECF_{init}) - \xi_{CI}(1 - CI/CI_b)\right) + \Delta ECF$$

$$\tau_{BW} \frac{d\Delta ECF}{dt} = \xi_{BW}(BW - BW_{init}) - \Delta ECF$$

$$TEE = TEF + PAE + RMR$$

$$RMR = E_c + \gamma_B M_B + \gamma_{FFM}\left[FFM - M_B - \Delta G(1+h_g) - (ECF - ECF_{init})\right] + \gamma_F F$$
$$+ (1-\varepsilon_d) DNL + (1-\varepsilon_g)(GNG_F + GNG_P) + (1-\varepsilon_K) KTG$$
$$+ \eta_N N_{excr} + (\eta_P + \varepsilon_P) D_P + \eta_P \frac{dP}{dt} + \eta_F D_F + \eta_F \frac{dF}{dt} + \eta_G D_G + \eta_G \frac{dG}{dt}$$

$$\tau_T \frac{dT}{dt} = \begin{cases} \lambda_1 (\Delta EI / EI_b) - T, & \text{if } EI < EI_b \\ \lambda_2 (\Delta EI / EI_b) - T, & \text{else} \end{cases}$$

$$\hat{\gamma}_{FFM} = \sum_i \gamma_i \frac{dM_i}{dFFM}$$

$$\gamma_{FFM} = \hat{\gamma}_{FFM}\left[1 + (1-\sigma)T\right]$$

$$PAE = \delta(1 + \sigma T) BW + \upsilon BW$$

$$TEF = \alpha_F FI + \alpha_P PI + \alpha_C CI$$

$$CarbOx = GNG_f + GNG_p - G3P + f_C \times \tilde{TEE}$$

$$FatOx = KetOx + f_F \times \tilde{TEE}$$

$$ProtOx = f_P \times \tilde{TEE}$$

$$DNL = \frac{CI \times (G/G_{init})^d}{(G/G_{init})^d + K_{DNL}^d}$$

$$D_G = \hat{D}_G \left(\frac{G}{G_{init}}\right)$$

$$D_P = \hat{D}_P \left[\left(\frac{P}{P_{Keys}}\right) + \chi\left(\frac{\Delta PI}{PI_b}\right)\right]$$

$$D_F = \hat{D}_F \left(\frac{F}{F_{Keys}}\right)^{\frac{2}{3}} \left[L_{diet} + L_{PA}\right]$$

$$\tau_L \frac{dL_{diet}}{dt} = \frac{K_L^{S_L}\left[1 + (A_L - B_L) \times \exp(-k_L CI/CI_b) + B_L\right]}{K_L^{S_L} + MAX\left\{0, (F/F_{Keys} - 1)^{S_L}\right\}} - L_{diet}$$

$$GNG_F = FI\left(\frac{\rho_C M_G}{\rho_F M_{TG}}\right) + D_F \rho_C \left(\frac{M_G}{M_{TG}}\right)$$

$$L_{PA} = \psi\left(\frac{\delta + \upsilon}{\delta_{init} + \upsilon_{init}} - 1\right)$$

$$GNG_P = \hat{GNG}_P \left[\left(\frac{P}{P_{Keys}}\right) - \Gamma_C\left(\frac{\Delta CI}{CI_b}\right) + (\Gamma_P + \chi)\left(\frac{\Delta PI}{PI_b}\right)\right]$$

$$KTG = \rho_K D_F \left[A_K \left(\frac{D_F/\hat{D}_F}{K_K + D_F/\hat{D}_F}\right) \exp\left(-k_P \frac{PI}{PI_b}\right) \exp\left(-k_G \frac{G}{G_{init}}\right)\right]$$

$$KU_{excr} = \begin{cases} 0, & \text{if } KTG/\rho_K < KTG_{thresh} \\ \dfrac{\rho_K KU_{max}(KTG/\rho_K - KTG_{thresh})}{(KTG_{max} - KTG_{thresh})}, & \text{else} \end{cases}$$

$$f_C = \frac{w_G (D_G/\hat{D}_G) + w_C MAX\{0, (1 + S_C \Delta CI/CI_b)\} G/(G_{min} + G)}{Z}$$

$$f_F = \frac{w_F (D_F/\hat{D}_F)}{Z}$$

$$f_P = \frac{w_P MAX\{0, (1 + P_{sig})\} + (D_P/\hat{D}_P) S_A \exp(-k_A(\delta + \upsilon)/(\delta_b + \upsilon_b))}{Z}$$

$$\tau_{PI} \frac{dP_{sig}}{dt} = S_P \Delta PI / PI_b - P_{sig}$$

Body Weight Planner | *Balancing Your Food and Activity*

Step 1 of 4 - Enter your starting information

Switch to Expert Mode

Starting Information

U.S. Units | Metric Units

Weight		lbs
Sex		
Age		yrs
Height	ft.	in.
Physical Activity Level	1.6	Estimate Your Level

Next Step

Starting Information

Enter your starting information, including your weight, sex, age, height, and physical activity level.

Physical Activity Level

Click the "Estimate Your Level" button to find your physical activity level.

Typical physical activity level numbers range from 1.4 (sedentary) to 2.5 (very active).

The default value of 1.6 describes someone who does very light activity at school or work (mostly sitting) and moderate physical activity (such as walking or cycling) at least once a week.

Disclaimer: This information is for use in adults defined as individuals 18 years of age or older and not by younger people, or pregnant or breastfeeding women. This information is not intended to provide medical advice. A health care provider who has examined you and knows your medical history is the best person to diagnose and treat your health problem. If you have specific health questions, please consult your health care provider.

3.1 Overview of Energy Systems

Overview of Energy Systems

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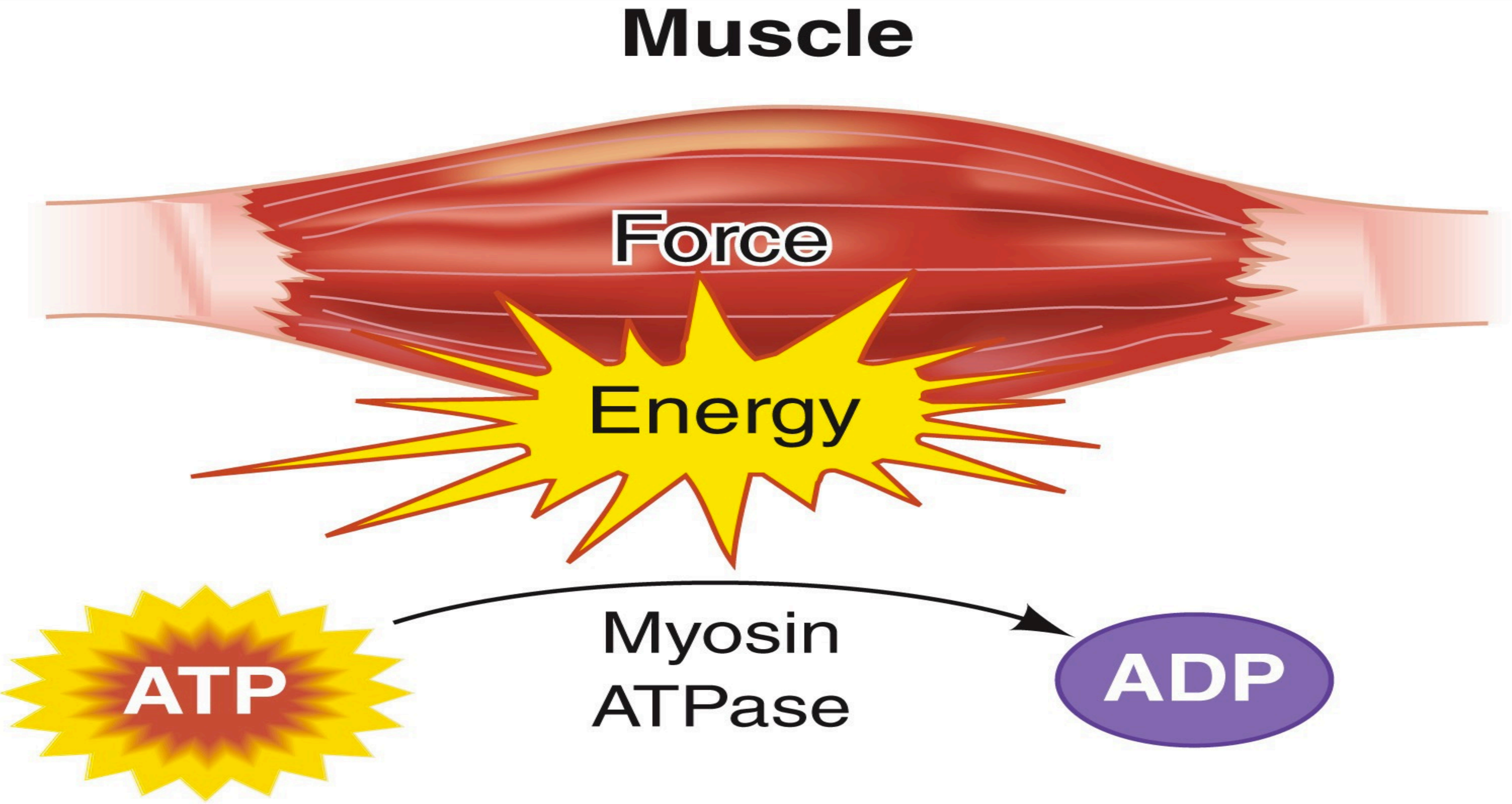
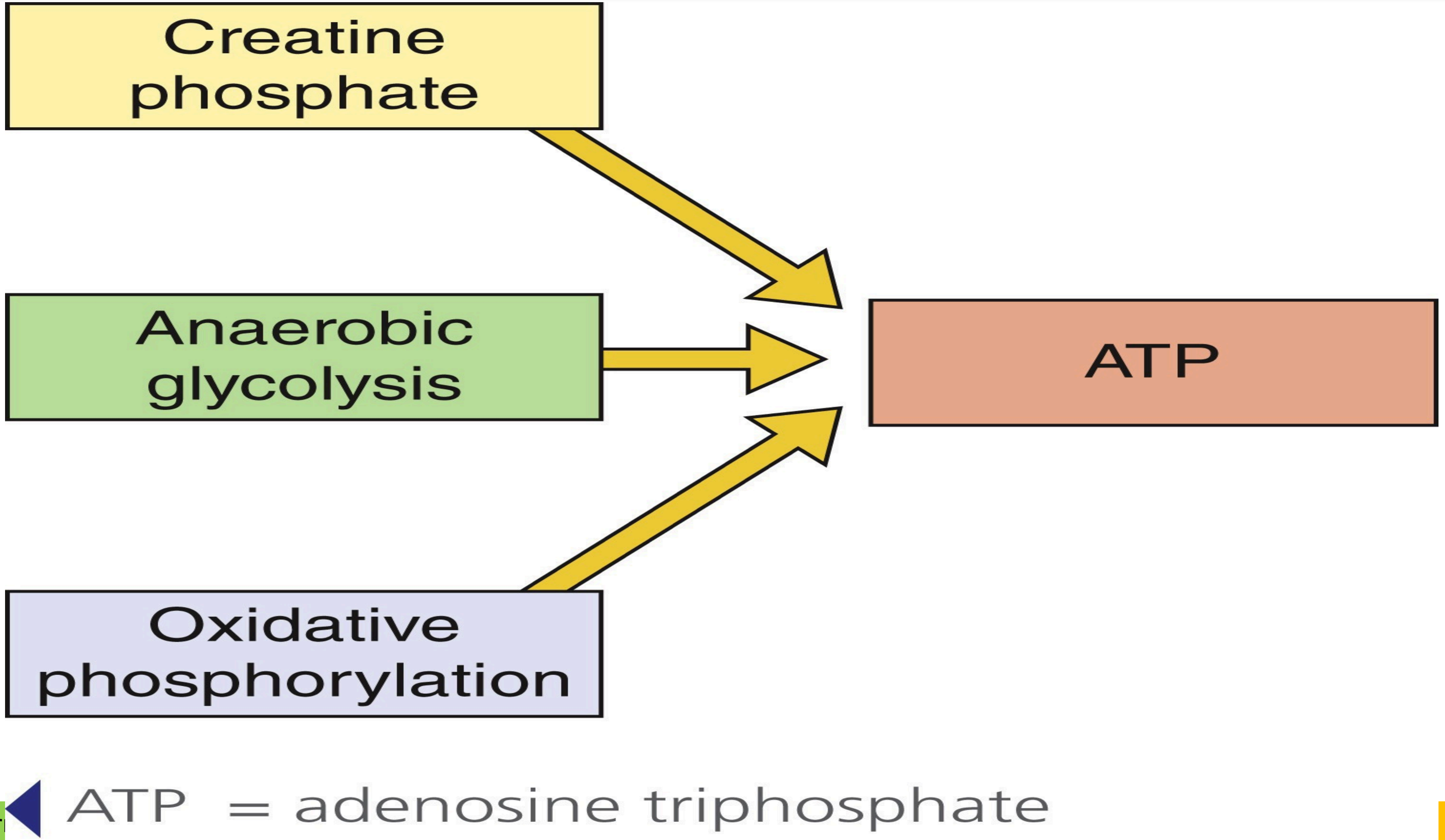


Overview of Energy Systems



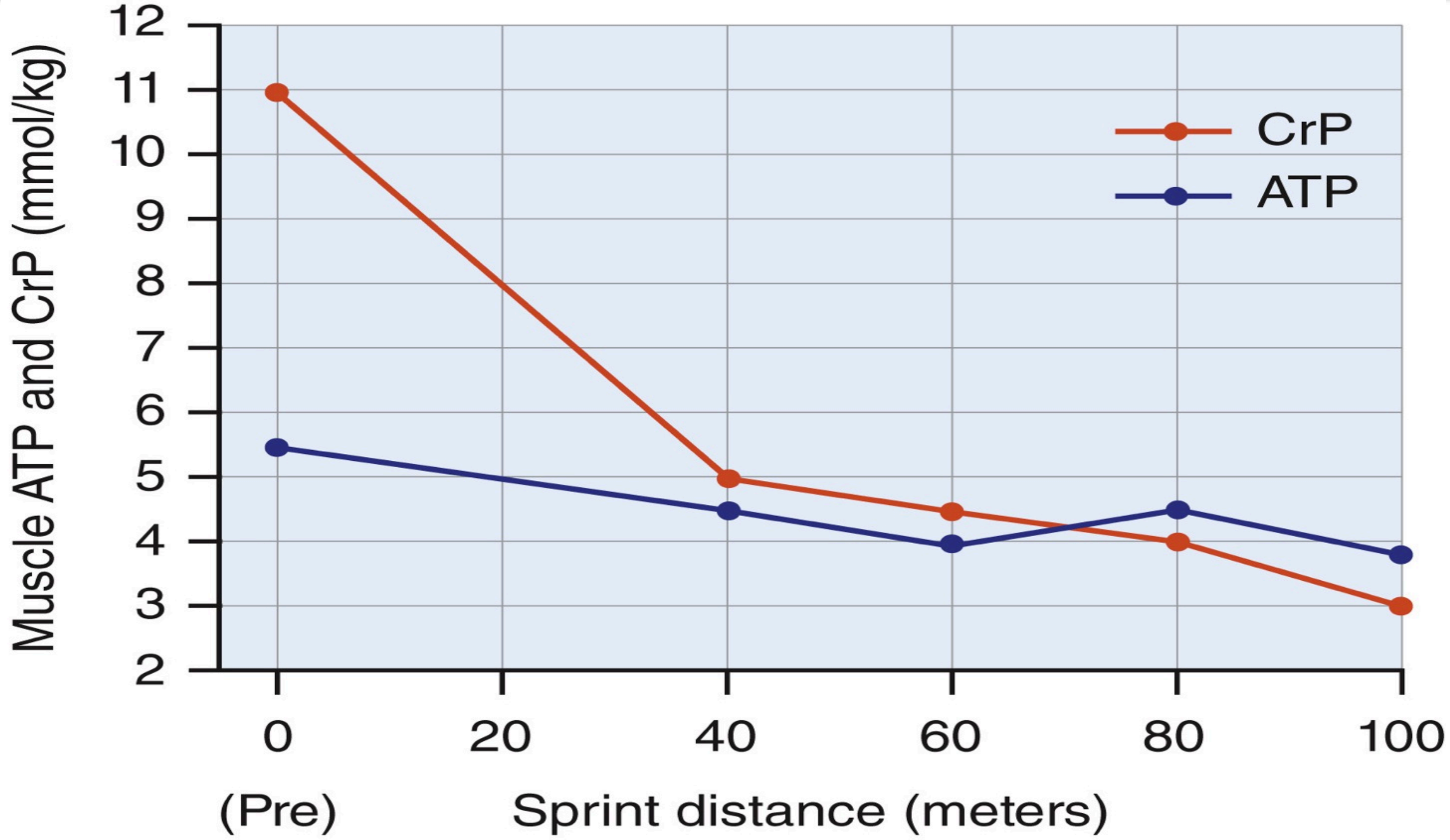
Overview of Energy Systems

Table 3.1 Characteristics of the Three Energy Systems

	Speed of action	Amount of ATP replenished	Duration of action
Creatine phosphate	Very fast	Very small	Very short
Anaerobic glycolysis	Fast	Small	Short
Oxidative phosphorylation	Very slow	Large	Very long

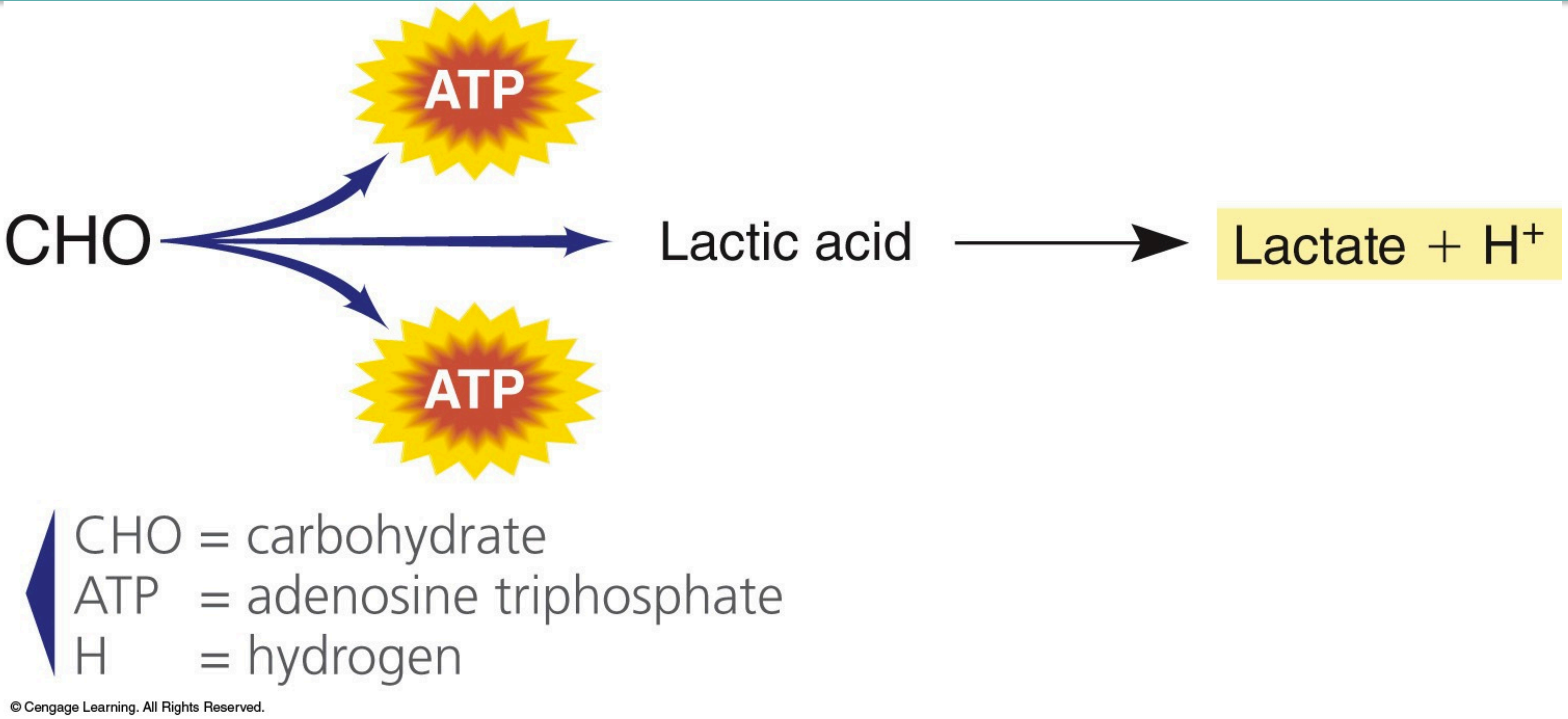
ATP = adenosine triphosphate

The Creatine Phosphate Energy System

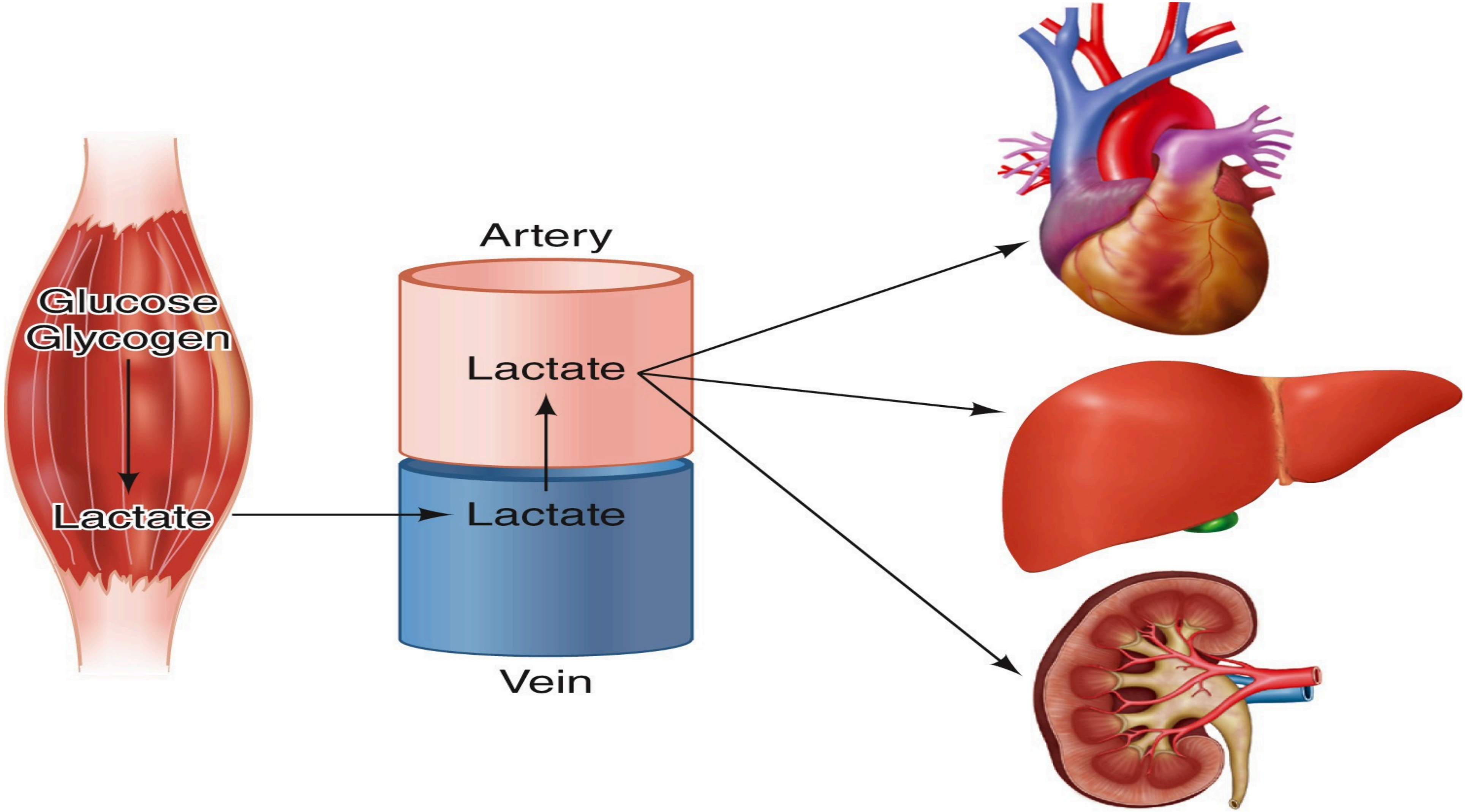


ATP = adenosine triphosphate
CrP = creatine phosphate
mmol/kg = millimoles per kilogram

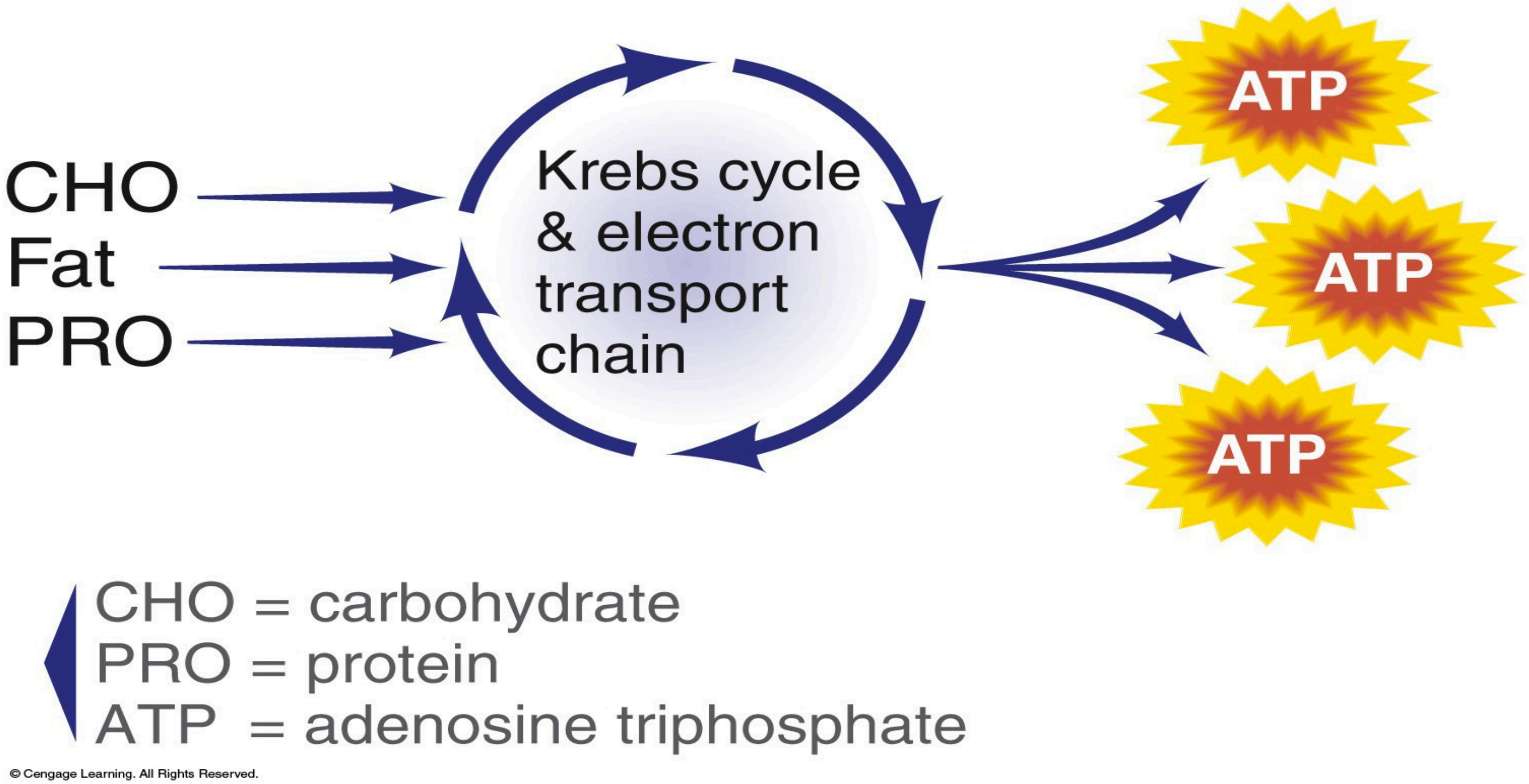
3.3 The Anaerobic Glycolysis Energy System



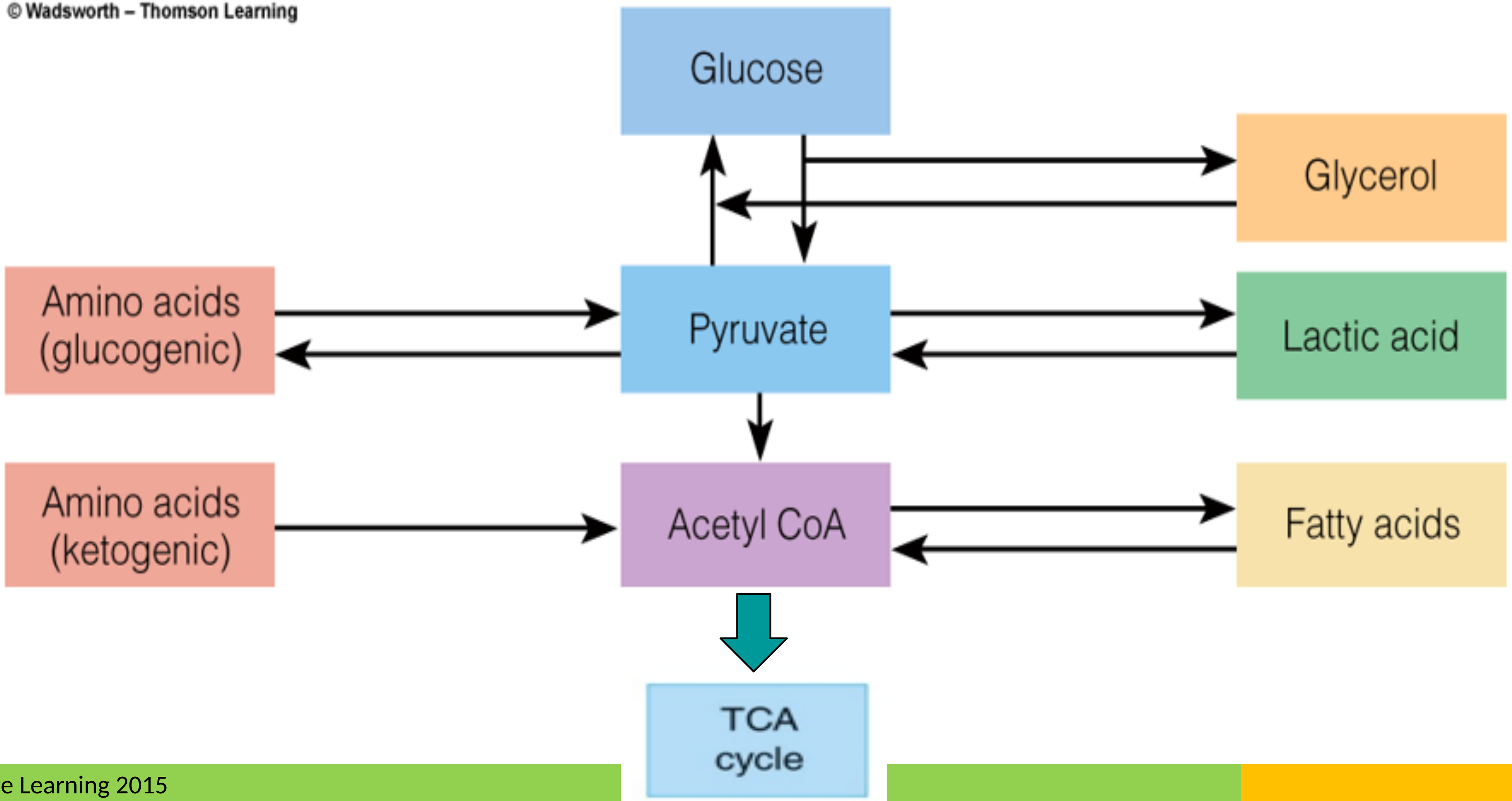
The Fate of Lactate



3.4 The Oxidative Phosphorylation Energy System



Energy Pathways



3.5 Fuel Utilization

- Fats are metabolized aerobically by the oxidation of fatty acids
- Lipolysis* is the term used for the breakdown of triglycerides
- Proteins are metabolized aerobically by the oxidation of amino acids
- The respiratory exchange ratio (RER) indicates utilization of carbohydrate and fat as fuels

- -lysis means to break down
  - Hydrolysis
  - Glycolysis

Fuel Utilization

RER = respiratory exchange ratio; CHO = carbohydrate

The RER calculated from measured $\dot{V}O_2$ and $\dot{V}CO_2$ can be used to determine the percentage of energy that is being derived from carbohydrate and fat oxidation. The full table can be seen in Appendix I.

Table 3.2 Nonprotein Respiratory Exchange Ratio and Percentages of Energy from Carbohydrates and Fats

RER	Percent CHO	Percent fat
0.70	0	100
0.75	15	85
0.80	32	68
0.85	49	51
0.90	66	34
0.95	83	17
1.00	100	0

Table 3.3 Metabolic Pathways Favored under Normal and Starvation Conditions

	Liver	Muscle	Adipose tissue	Central nervous system (CNS)
Fed (absorptive) state	Glucose used as energy, stored as glycogen, and converted to fatty acids if energy intake is greater than expenditure; amino acids metabolized; fatty acids transported to adipose tissue for storage as triglycerides	Glucose used for energy or stored as glycogen	Fatty acids are stored as triglycerides (three fatty acids + glycerol)	Glucose from food used to provide energy
Postabsorptive state	Glycogen broken down to provide glucose; manufacture of glucose from lactate and alanine (provided by muscle) and glycerol (provided by the breakdown of fat from adipose tissue) begins	Glucose used for energy, some glycogen storage continues; lactate and alanine released to liver to make glucose; fatty acid uptake (provided by the breakdown of fat from adipose tissue) for use as energy	Triglycerides are broken down to provide fatty acids to muscle and liver; glycerol to liver to be used for glucose	Glucose comes predominantly from liver glycogen
Fasting (18 to 48 hours without food)	Liver glycogen is depleted; glucose made from lactate and amino acids provided by muscle; red blood cells also provide some lactate	Muscle protein degraded to provide amino acids to liver; lactate to liver for glucose synthesis	Same as above	Glucose provided by the liver (from lactate and amino acids)
Starvation (>48 hours without food)	Liver continues to manufacture glucose, predominantly from glycerol (from adipose tissue) to prevent muscle from providing amino acids and lactate; fatty acids broken down to produce ketones (for use by CNS and muscle)	Muscle depends predominantly on fatty acids and ketones for energy	Triglycerides are broken down to provide fatty acids to muscle and liver; glycerol to liver to be used for glucose	CNS depends primarily on ketones produced by the liver for energy

Summary

- The direct source of energy for most cellular processes is ATP
- Creatine phosphate, anaerobic glycolysis, and oxidative phosphorylation are the three major energy systems
- These three energy systems work in concert although one energy system usually predominates

Summary

- Each energy system has distinct advantages (e.g., speed, amount produced, duration) and limitations (e.g., speed, amount produced, duration, depletion of substrate, undesirable effects)
- Carbohydrates, proteins, and fats can be metabolized aerobically through the oxidative phosphorylation energy system
- As exercise intensity increases above moderate levels, carbohydrates become the predominant fuel source for energy expenditure