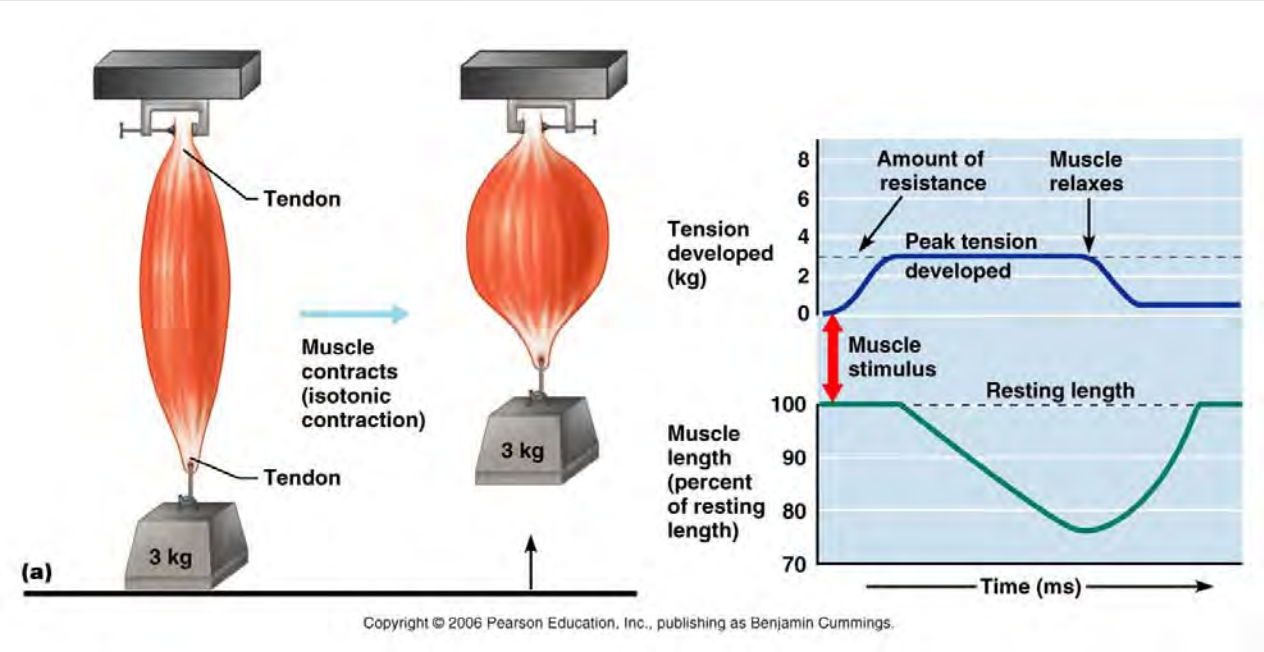
Muscles 3:

Contractions, Adaptations & Energy Use

Contractions

- **Isotonic**: Muscle changes length in response to resistance
  - Concentric: muscle **tension exceeds resistance** & *muscle shortens*
  - Eccentric: **Resistance exceeds muscle tension** and *muscle lengthens*
- **Isometric**: muscle **tension does not exceed resistance** and muscle length remains constant

Isotonic



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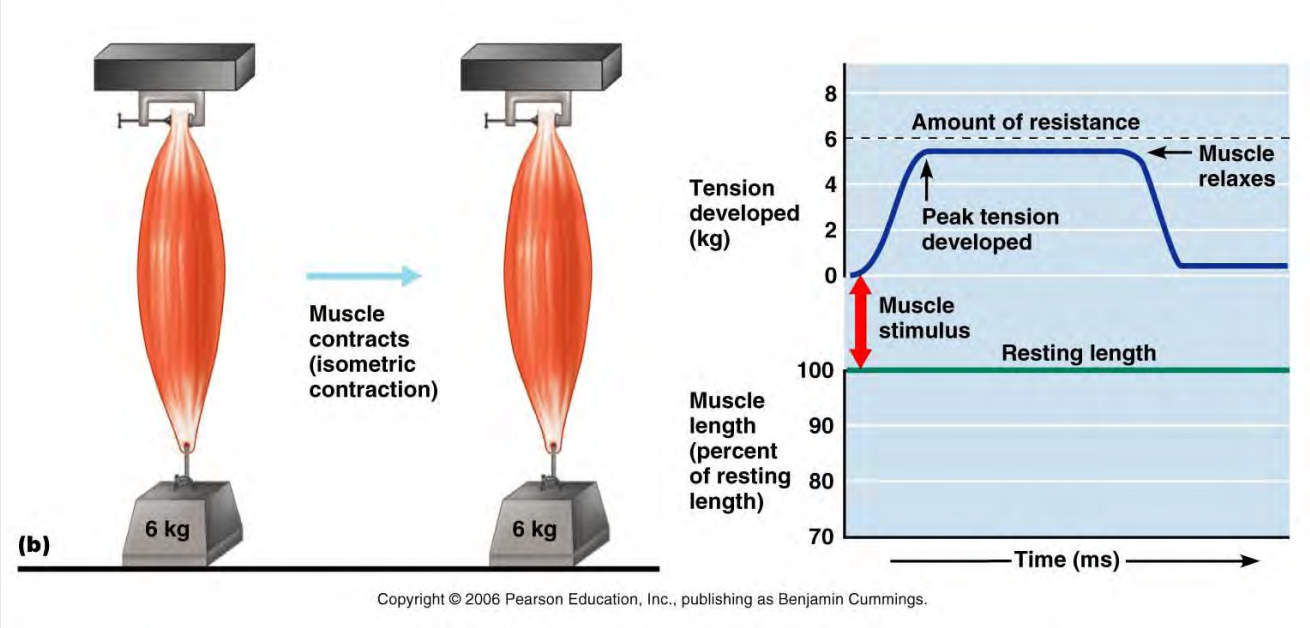
- Tension exceeds Resistance just enough to produce movement
- Muscle shortens as long as Tension > Resistance
  - Ex: lifting this pen

Isometric



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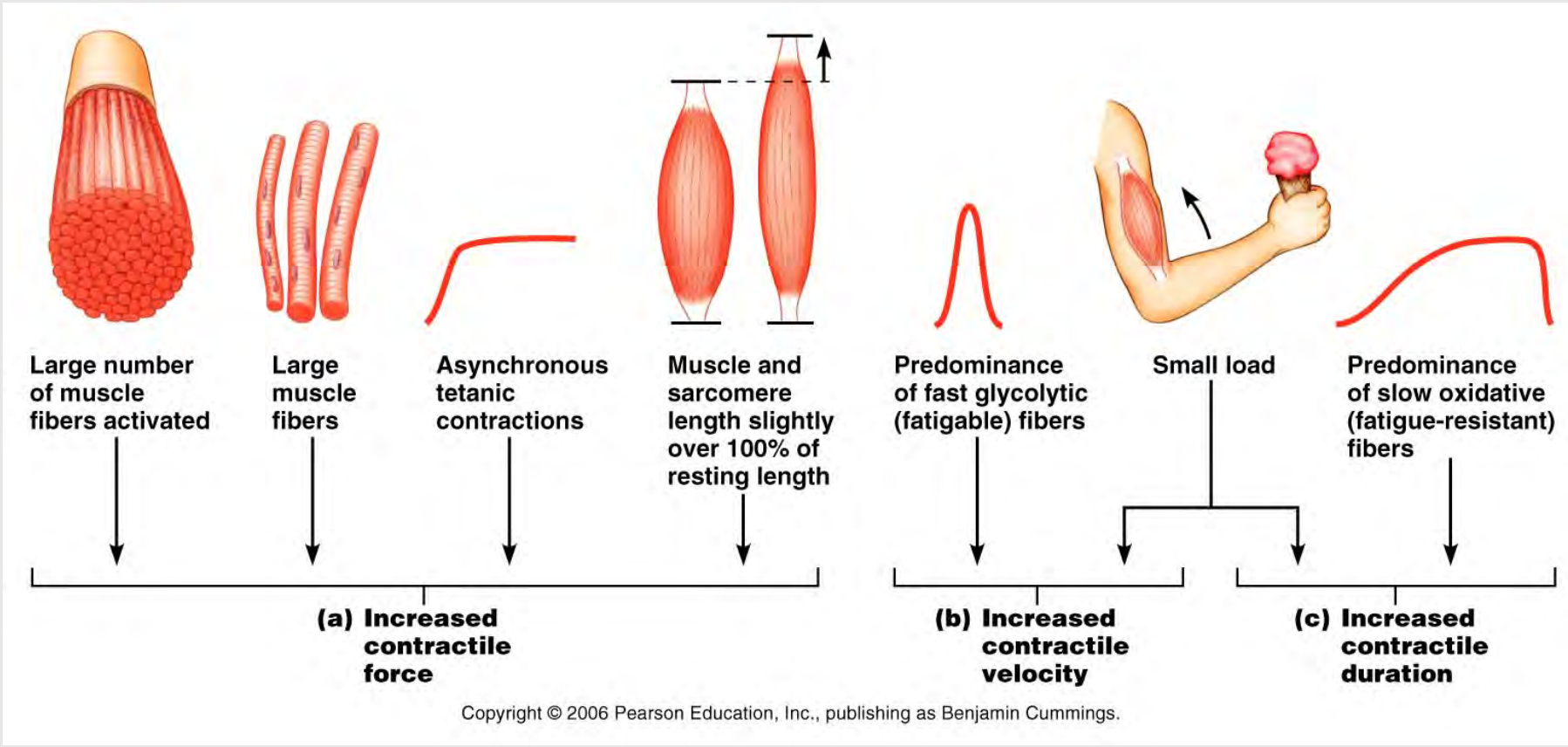
- Tension *does not* exceed Resistance
- Muscle remains same length (isometric) as long as Tension < Resistance
  - Ex: pushing against this wall

What affects Tension and speed of contraction?



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What fuels our muscles?

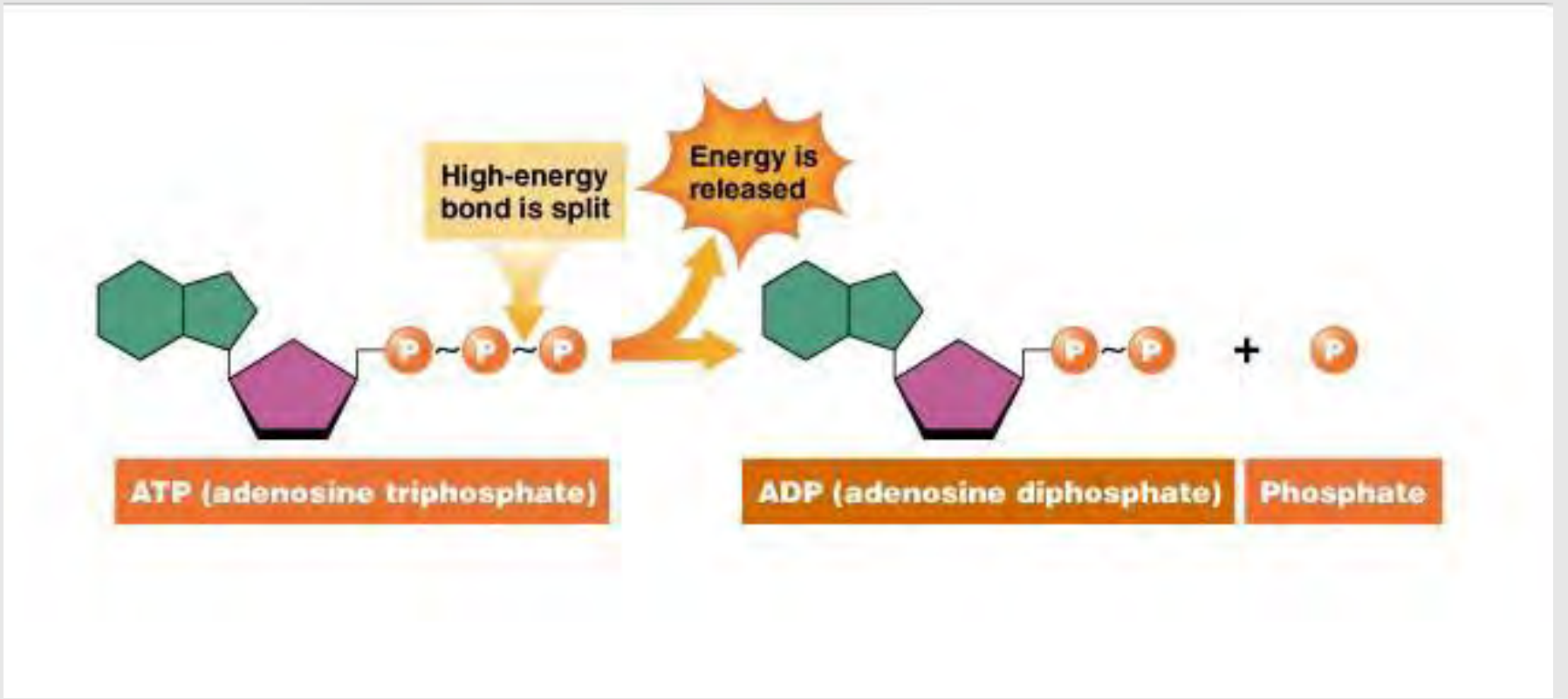
1. Adenosine triphosphate (**ATP**)
2. Creatine Phosphate (**CP**)
3. Glucose
4. Fats

What fuels our bodies?

- Adenosine triphosphate (ATP) – **THE** energy carrying molecule in the body

- Muscles store only enough ATP for 1 – 3 sec. of activity (~ 10 twitches)
  - ATP must be generated continuously
    - Usually via carbohydrate metabolism **with** or **without** O_2

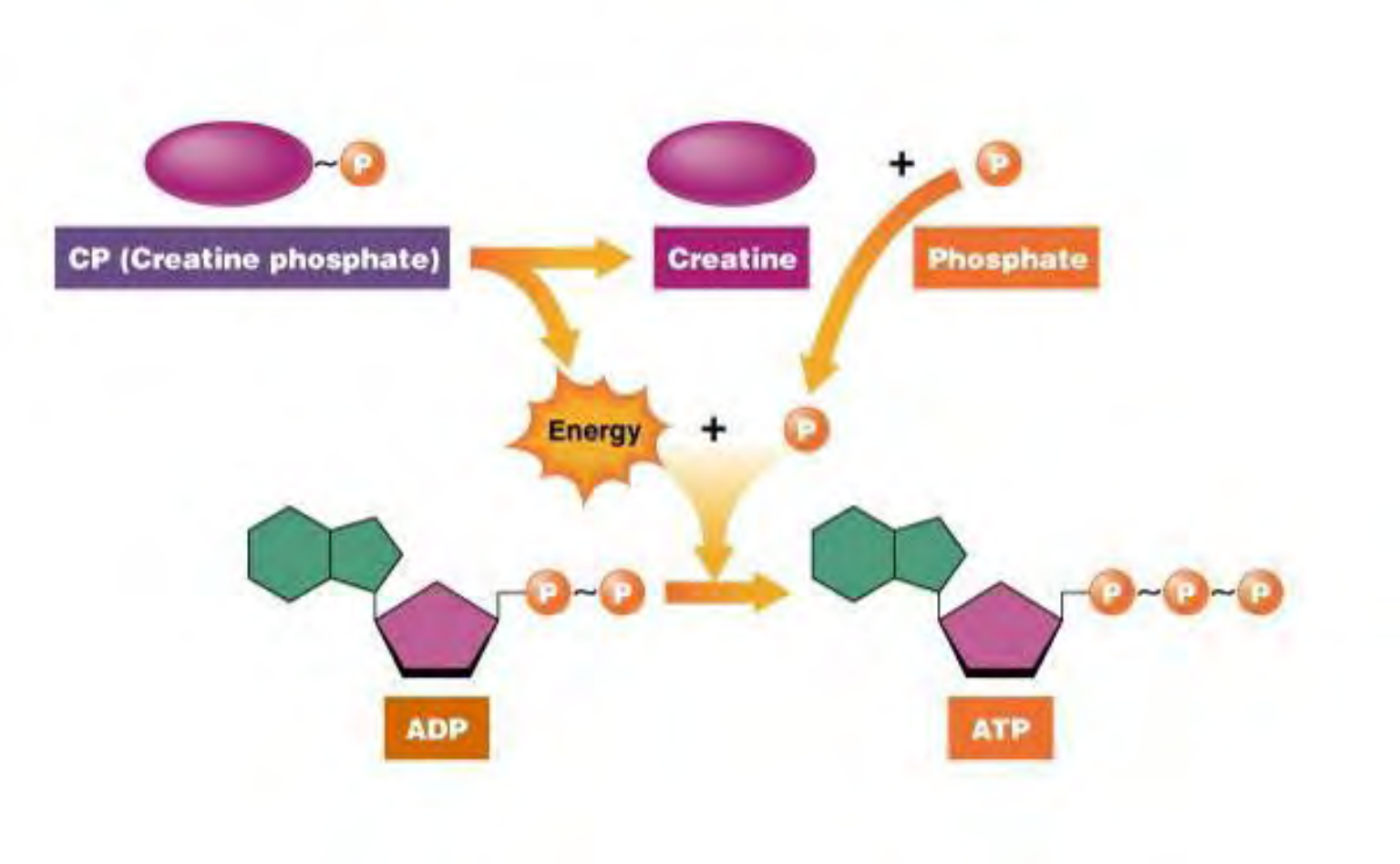
ATP structure



Alternative Fuels

- After depleting ATP stores, muscles turn to **other** sources:
  - Creatine phosphate (CP) stores energy, in the form of a bound phosphate molecule, that is used to make ATP
  - CP stores enough energy for ~ 15 sec. of muscle contractions (~ 70 twitches)

CP transfers P to make ATP



Glucose (Glycogen)

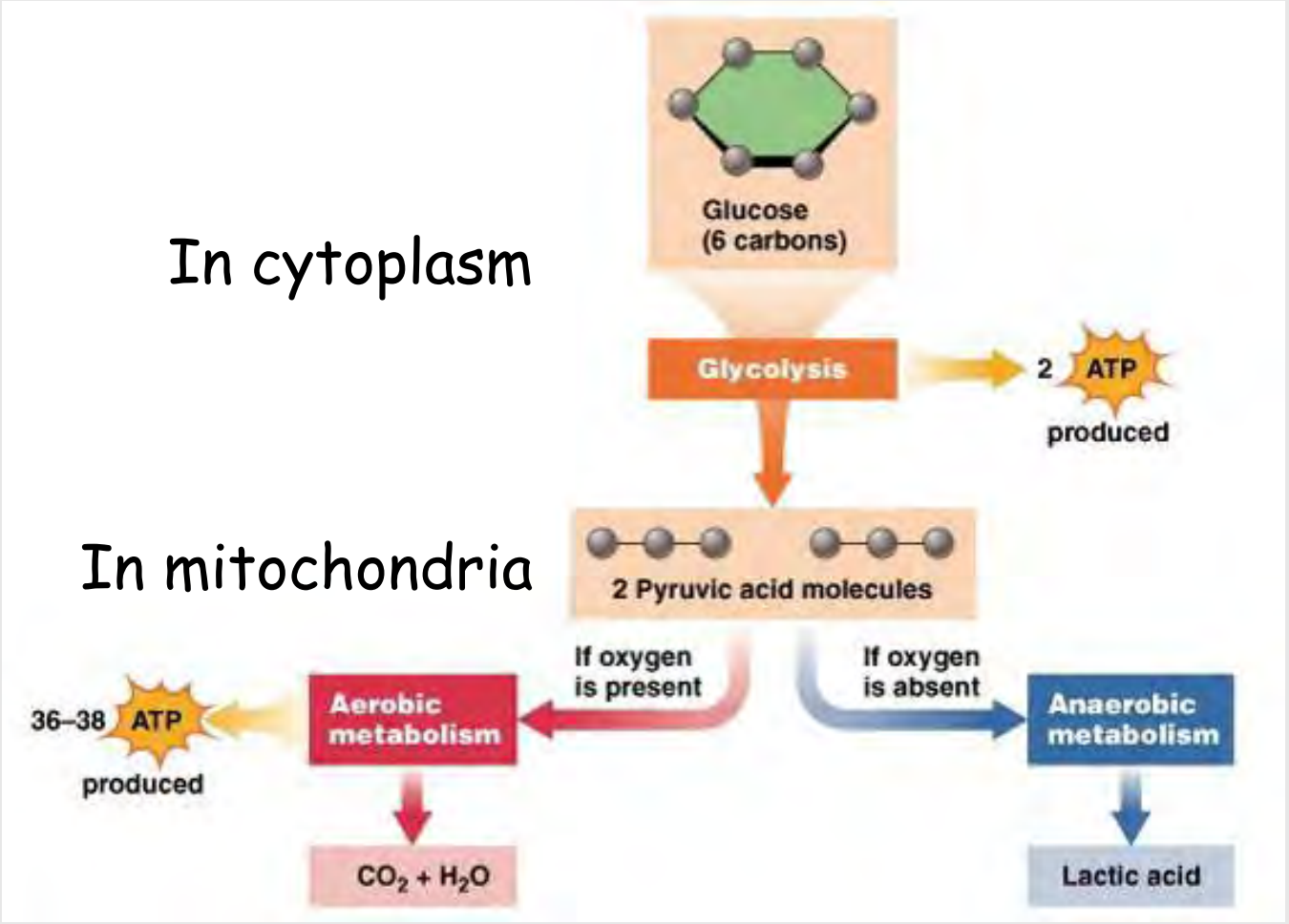
- After CP, Glucose is the next source of energy for production of ATP

- Metabolism of glucose
  - Anaerobic breakdown of glucose (glycolysis) yields 2 ATP molecules (no O_2 needed), & provides energy for ~ 130 sec. of contractions (670 twitches)
  - Aerobic breakdown of glucose yields 36 – 38 molecules of ATP (*demands* O_2), & provides Energy for 2400 sec. (12,000 twitches)

Glucose metabolism

In cytoplasm

In mitochondria

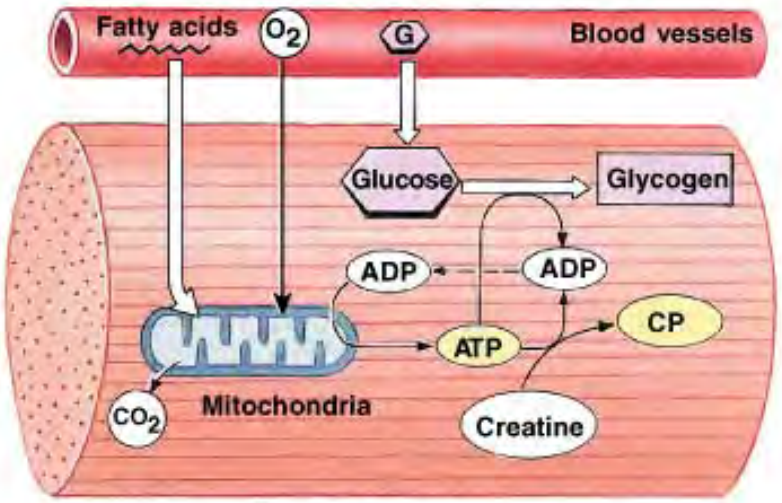


Fat as fuel

- Triglycerides (storage form of fats) can be metabolized to generate ATP
  - For low intensity exercise
  - For exercise of **long** duration
    - Ex: 10 hr. car-to-car approach + climb
  - Abundant energy source, even in lean people
  - Provides 2x **more** energy, per gram, as carbohydrate

Resting muscle

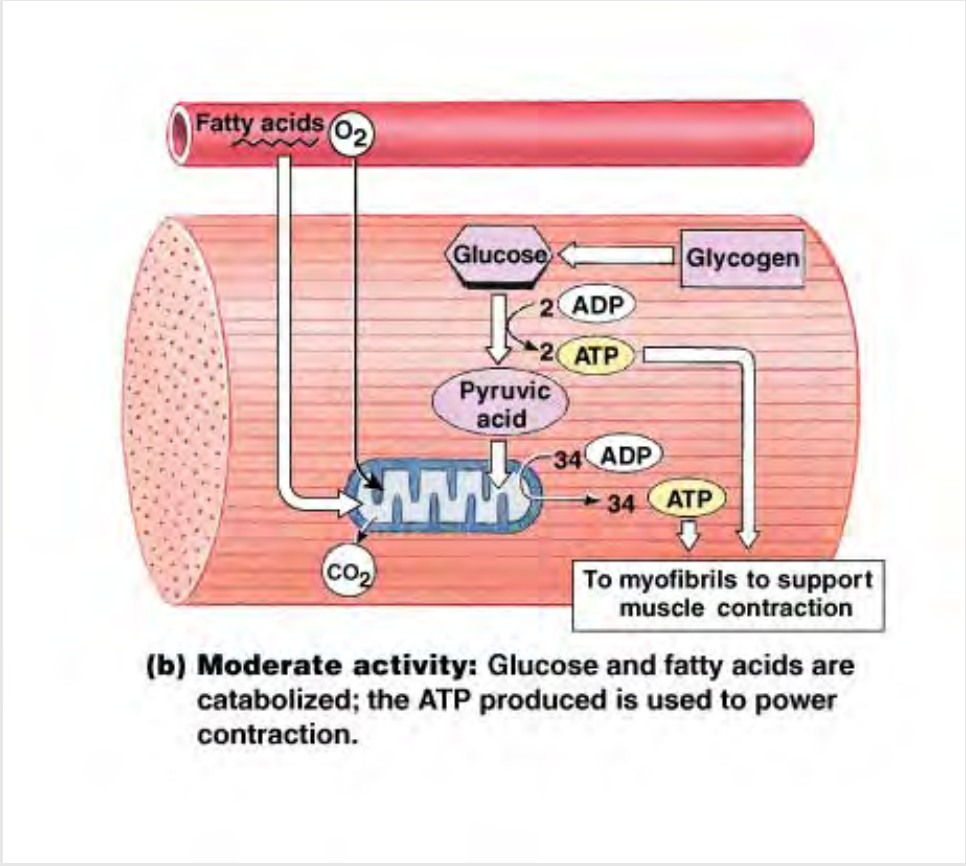
- Plenty of O_2 around
- Fatty acids are "burned" through **aerobic metabolism** to make reserves of ATP, CP & glycogen



(a) Resting muscle: Fatty acids are catabolized; the ATP produced is used to build energy reserves of ATP, CP, and glycogen.

Moderate muscle activity

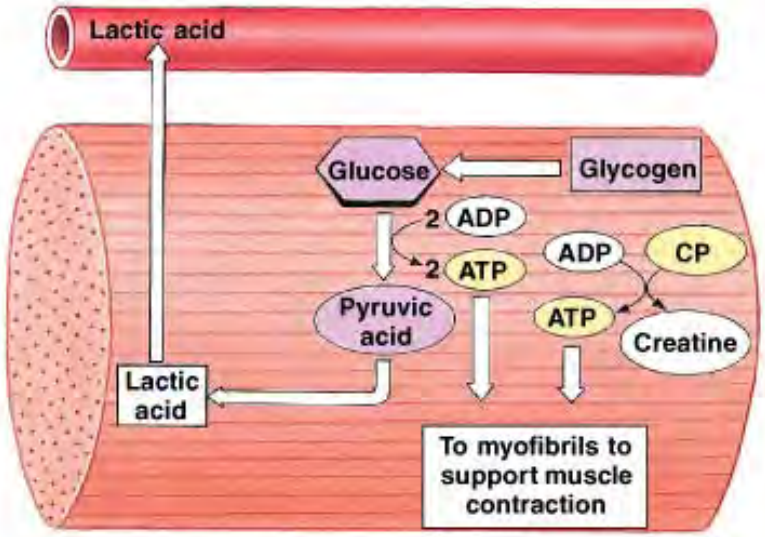
- Enough O_2 around
- Fatty acids and glucose "burned" through **aerobic metabolism** to make ATP as it is used up to power contractions



(b) Moderate activity: Glucose and fatty acids are catabolized; the ATP produced is used to power contraction.

Peak muscle activity

- Not enough O_2 around
- Most (~ 66%) ATP produced via glycolysis.
  - **Lactic acid** is byproduct
    - At high concentrations, interferes with actin-myosin binding & other cellular enzymes



(c) Peak activity: Most ATP is produced through glycolysis, with lactic acid as a by-product. Mitochondrial activity (not shown) now provides only about one-third of the ATP consumed.

Muscle fatigue

- When a muscle can no longer perform at required activity level
- Causes:
  - Not enough energy (ATP, CP, Glycogen)
  - Too many waste products:
    - Drop in blood pH (due to high lactic acid and CO_2 concentrations)
    - Drop in muscle fiber pH (same cause), reduces Ca^{2+} binding efficiency and protein interactions

Muscle fiber **types** = Continuum

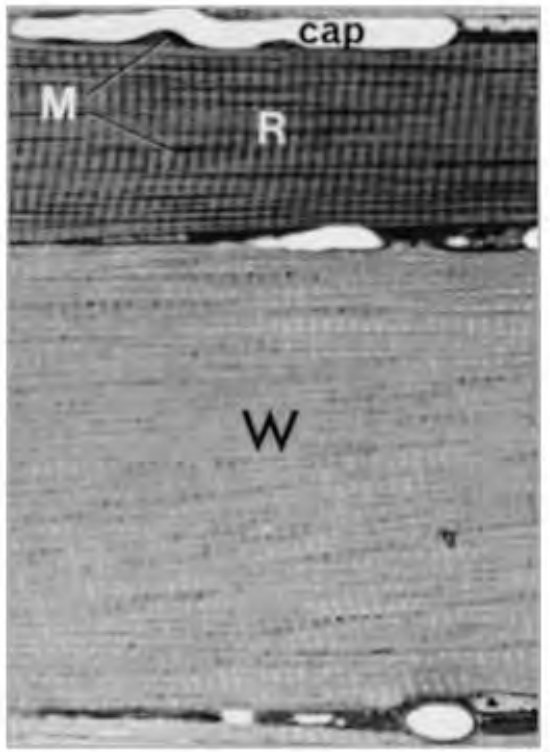
Fast twitch

- Large diameter
- rapid contraction phase
- few mitochondria
- poor vascularization
- huge ATP hogs

Slow twitch

- Small diameter
- slow contraction phase
- tons of mitochondria
- heavily vascularized
- Lots of myoglobin (O_2 storage protein)

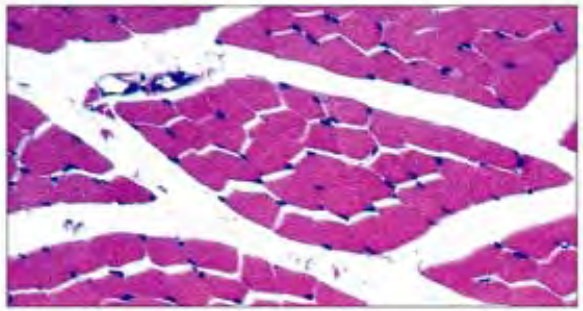
Fast vs. Slow



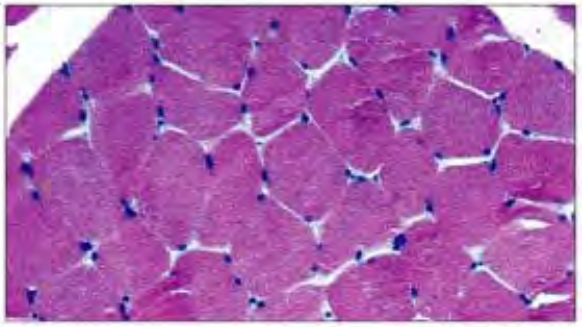
(a) LM × 783

Slow fibers
Smaller diameter, darker color due to myoglobin; fatigue resistant

Fast fibers
Larger diameter, paler color; easily fatigued



Slow LM × 171



(b) Fast LM × 171

Muscle Adaptations

- "Rapid" adaptations
- "Long-term" adaptations
- Read the article!

Muscle Adaptations

"Rapid" adaptations

- Increase glycogen storage
- Increase ATP and CP storage
- Increase glucose transport proteins
- Increase neuromuscular coordination

"Long-term" adaptations

- Increased mitochondrial density
- Increased capillary density
- Hypertrophy: increase in **size** of fibers
  - **Only** caused by repeated exhaustive stimulation

Physical conditioning (training)

Anaerobic endurance

- Muscle activity supported by energy reserves and glycolysis alone
- Affected by:
  - ATP & CP
  - Glycogen stores
  - Tolerance of lactic acid

Aerobic endurance

- Muscle activity supported by mitochondrial activities
- Affected by:
  - Substrates available for aerobic respiration (fats, carbs, proteins)