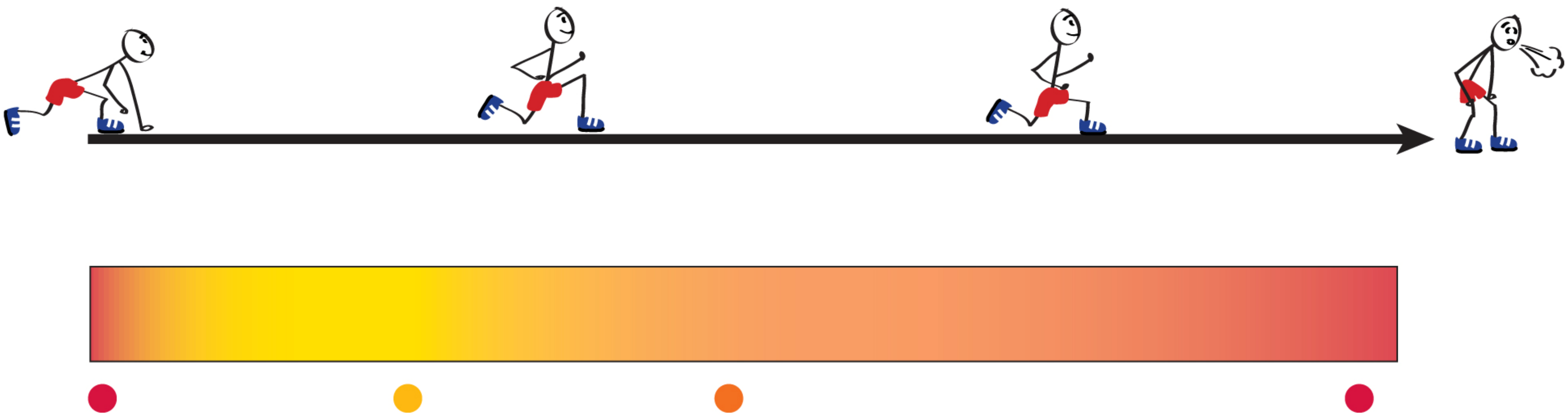
Chapter 10.5

Muscle Energy and Metabolism



Muscle “Energy” Metabolism

- All muscle contraction depends on ATP
- ATP is not stored in body
- You make ATP and then use it as we produce it!
- Ability to make new ATP supply depends on availability of organic energy sources // glucose and/or fatty acids
- Ability to make the amount of ATP also dependant on the presence or absence of oxygen
  - Glycolysis vs Kreb’s Cycle (also called citric acid cycle)

Muscle Metabolism

- Two main pathways of ATP synthesis
  - First metabolic pathway: anaerobic fermentation (glycolysis)
    - enables cells to produce ATP in the absence of oxygen / takes place in cytoplasm
    - yields little ATP and toxic lactic acid
    - Believed to be factor in muscle fatigue

Muscle Metabolism (Cont)

– Second metabolic pathway: aerobic respiration (Kreb's Cycle / Citrus Acid Cycle)

- Requires oxygen
- produces much more ATP // glycolysis = 2 vs Kreb's Cycle = 36 to 38
- less toxic end products CO_2 // glycolysis produces lactic acid
- Produces metabolic water
- Reduces FAD and NAD / these oxidized via electron transport system to produce most of the ATPs associated with the Kreb's Cycle // two ADP are directly phosphorlated within mitochondria during each "cycle"
- requires a continual supply of oxygen
- Takes place in the mitochondria

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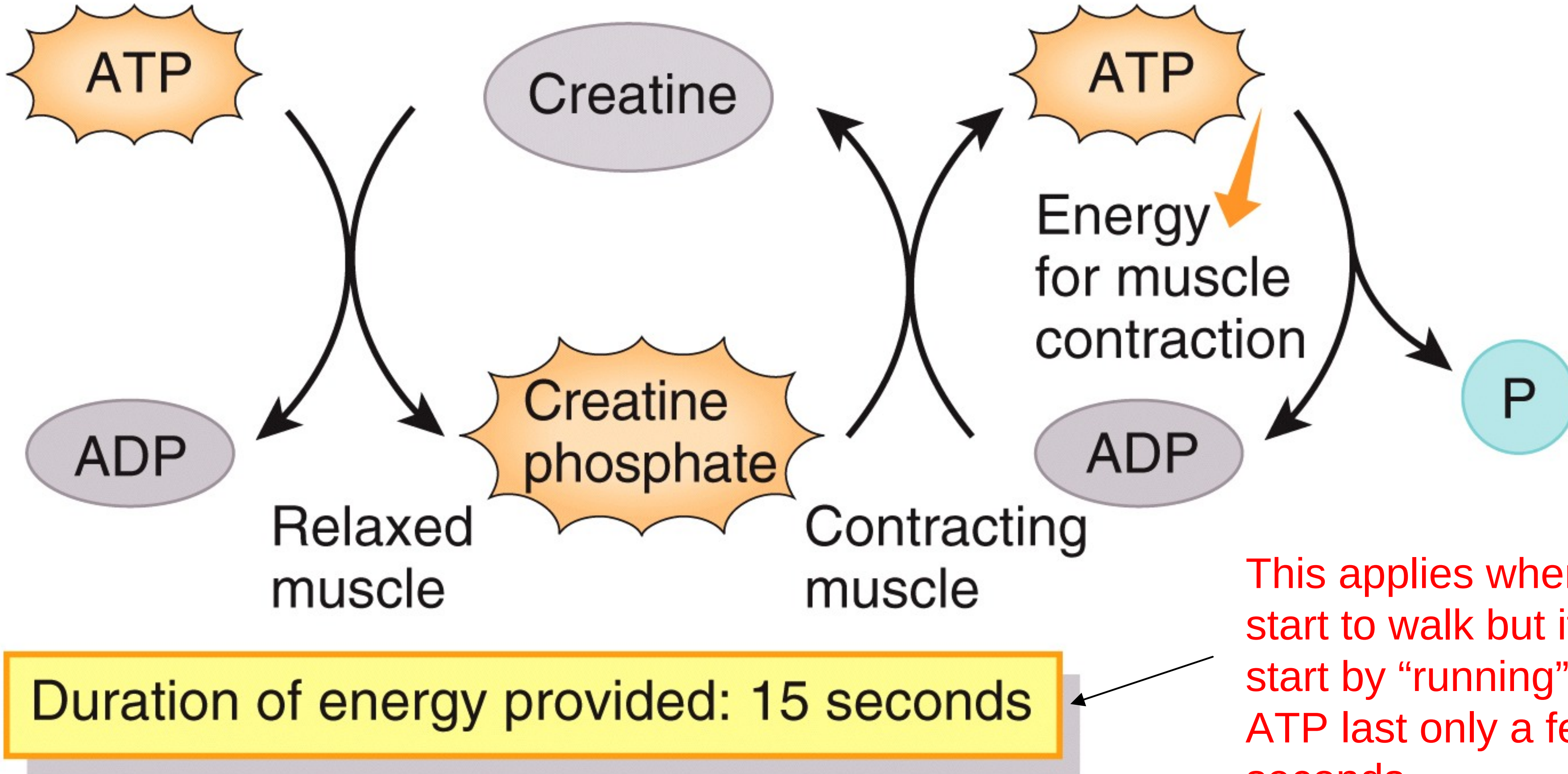
Key Idea: The level of activity (how fast the muscle fiber uses glucose and oxygen) determines the physiology of the muscle fiber. To support a high level of muscle contractions you need to increase the blood supply (delivery of glucose and oxygen) to the muscle fiber. This “ramp-up” means the cardiovascular and respiratory systems must increase their activities to meet the demands of the more active muscle organ. The muscle fiber must have a mechanism to “bridge” the metabolic requirements during this period. This dynamic plays out differently for example between walking and running.

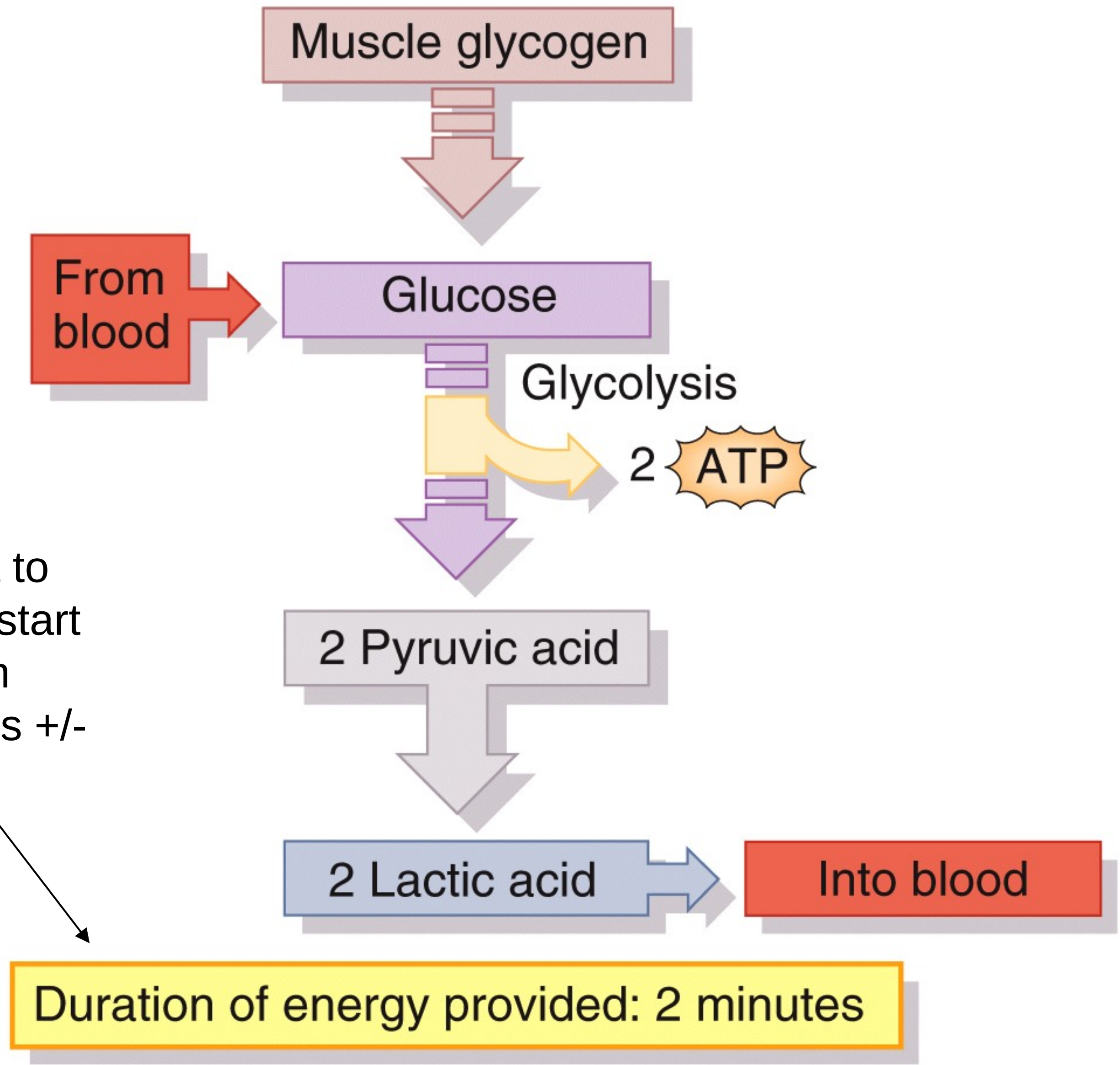


This applies when you start to walk but if you start by "running" then ATP last only a few seconds

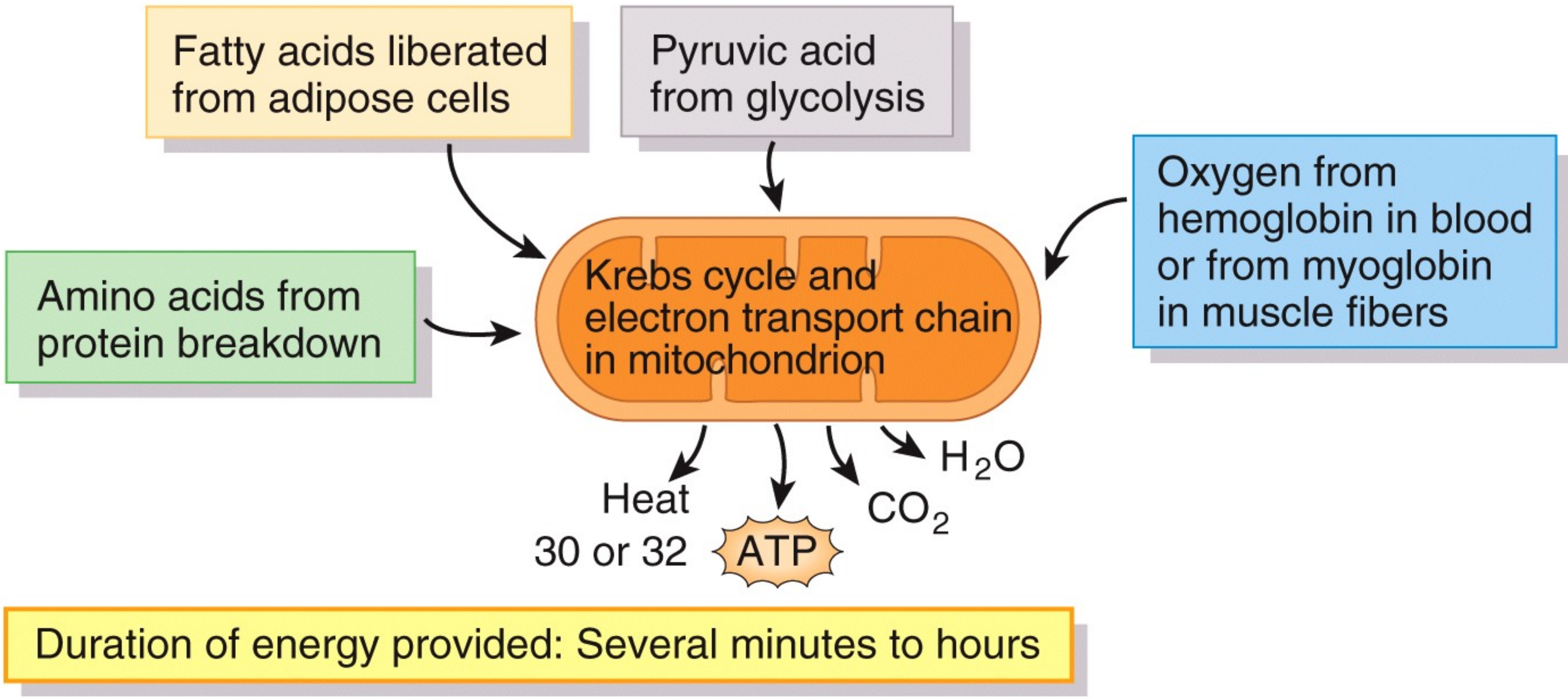
(a) ATP from creatine phosphate

Note: myoglobin releases oxygen / mitochondria can use this oxygen and limited amount from blood but only enough oxygen available to work muscle for a few seconds. Creatine phosphate and phosphogen systems generate ATP during initial contractions.

When you start to walk but if you start by “racing” then only 30 seconds +/-

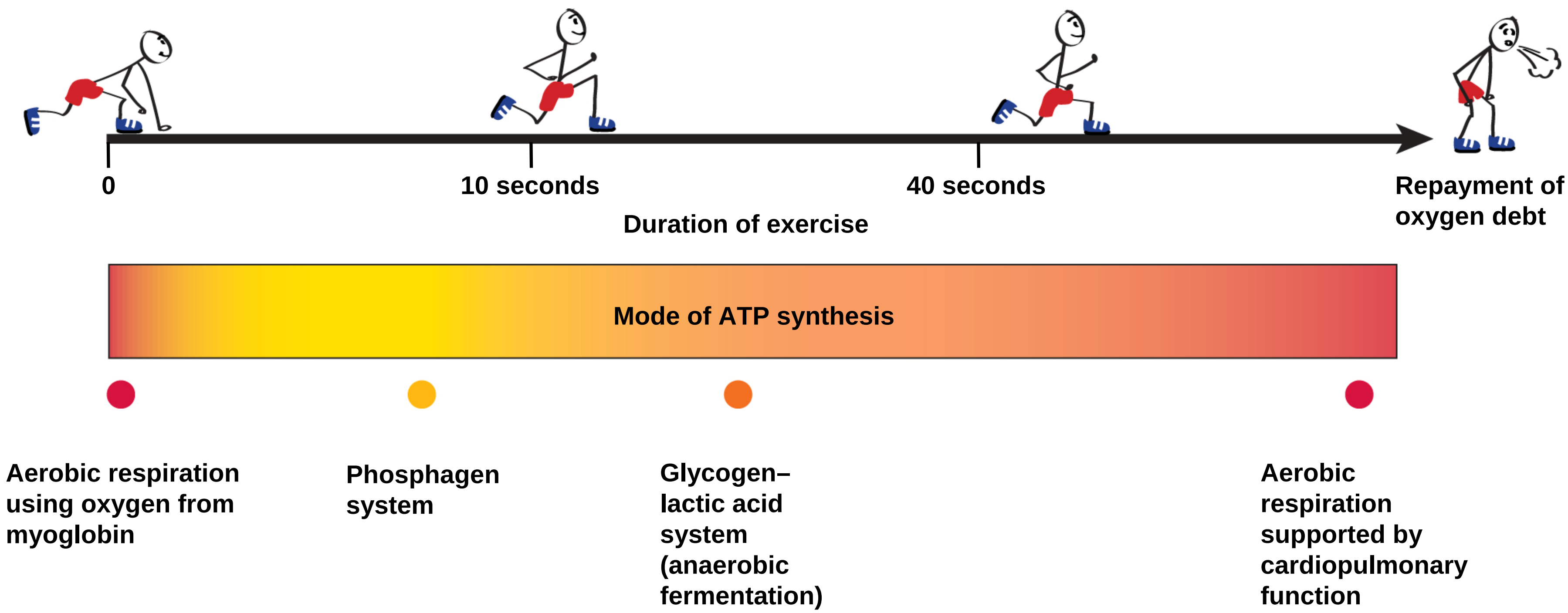


(b) ATP from anaerobic glycolysis



(c) ATP from aerobic respiration

Modes of ATP Synthesis During Extreme Exercise



At rest we oxidize fatty acids to supply energy for our skeletal muscles (note: our brains continue to oxidize glucose / brain cells and RBCs only ferment glucose)

As level of activity increases, skeletal muscles will shift from fat to glucose as an energy source.

Only after glucose reserves exhausted // shift back to fat metabolism

Immediate Energy Needs

- During short, intense exercise like 100 m dash
- Skeletal muscles start to contract before blood supply to muscle organ increases to meet metabolic needs (e.g. blood brings oxygen, glucose, and removes waste products)
- S.M. contain limited amount of myoglobin / stores small amount of oxygen inside muscle fibers
  - Maybe used to accommodate some aerobic respiration
  - Myoglobin's oxygen rapidly depleted

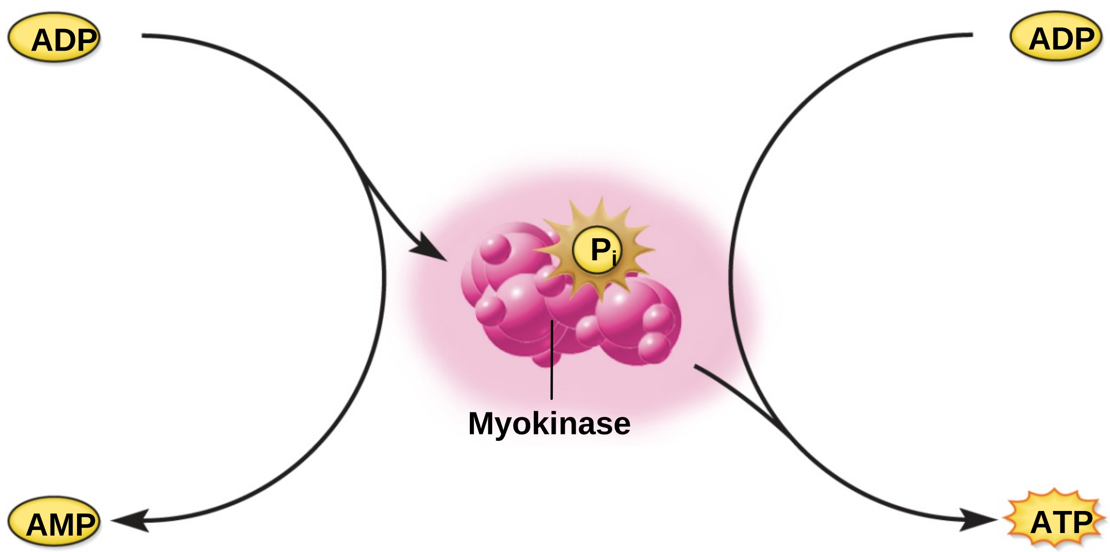
Immediate Energy Needs

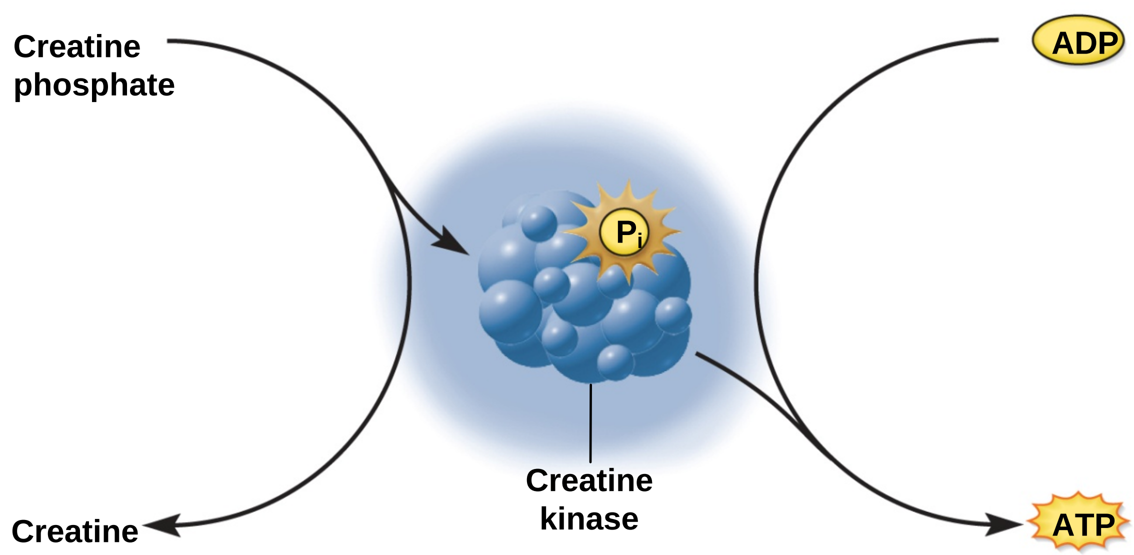
- After myoglobin gone / muscles meets ATP demand by borrowing phosphate groups (P_i) from other molecules and transferring the P_i to ADP (makes ATP!) = Phosphogen System
  - two enzyme systems control these phosphate transfers
    - myokinase – transfers P_i from one ADP to another converting the latter to ATP
    - creatine kinase – obtains P_i from a phosphate-storage molecule creatine phosphate (CP)
    - fast-acting system that helps maintain the ATP level while other ATP-generating mechanisms are being activated

Immediate Energy Needs

- Phosphagen system
  - provides nearly all energy used for short bursts of intense activity
    - one minute of brisk walking
    - 6 seconds of sprinting or fast swimming
    - important in activities requiring brief but maximum effort // football, baseball, and weight lifting

Immediate Energy Needs





Short-Term Energy Needs

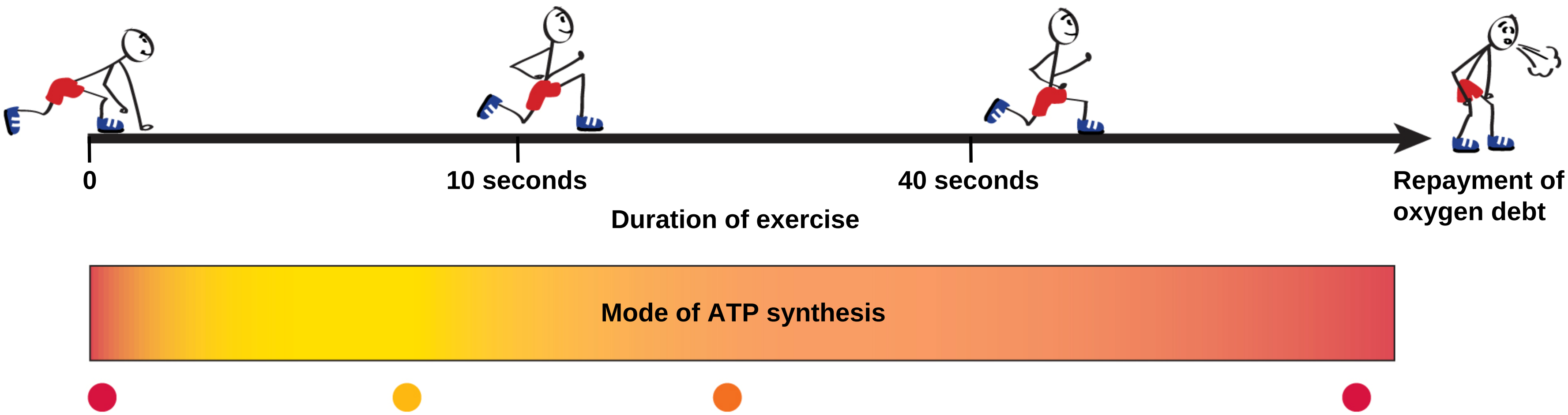
- as the phosphagen system is exhausted
- muscles shift to anaerobic fermentation
  - muscles obtain glucose from blood or muscle fiber’s stored glycogen deposits
  - in the absence of oxygen
    - glycolysis can generate a net gain of 2 ATP for every glucose molecule consumed
  - converts glucose to lactic acid / L.A. leaves cell and transported to liver

Short-Term Energy Needs

- **glycogen-lactic acid system //** the pathway from glycogen to lactic acid

- produces enough ATP for **30 – 40 seconds** of maximum activity

Long-Term Energy Needs

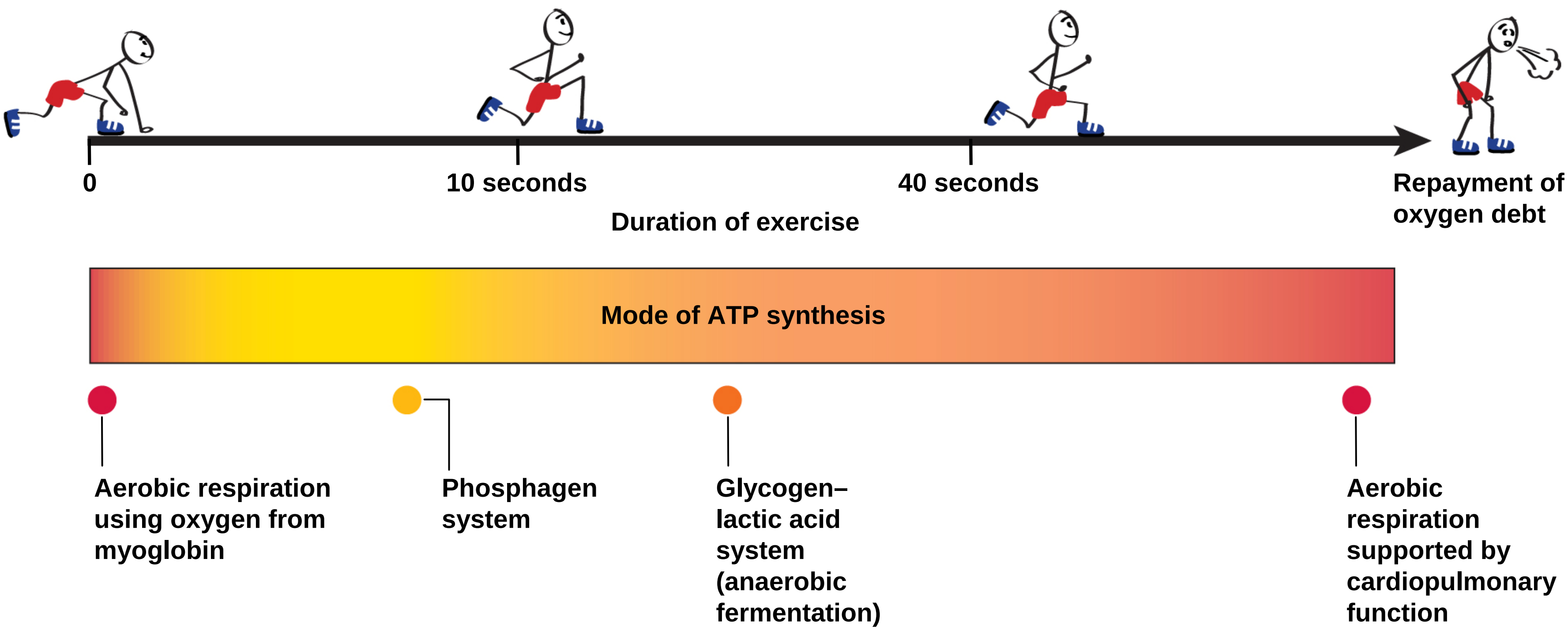


- After 40 seconds or so
  - respiratory and cardiovascular systems “catches up” to demands of skeletal muscles
  - now cardiorespiratory systems deliver enough oxygen to meet muscle’s oxygen requirement for aerobic respiration in mitochondria and enough ATP can be made to sustain muscle contrations.

Long-Term Energy Needs

- aerobic respiration produces 36-38 ATP per glucose
  - efficient means of meeting the ATP demands of prolonged exercise
  - one's rate of oxygen consumption rises for 3 to 4 minutes and levels off to a steady state in which aerobic ATP production keeps pace with demand
  - little lactic acid accumulates under steady state conditions
  - *depletion of glycogen and blood glucose, together with the loss of fluid and electrolytes through sweating, set limits on endurance and performance even when lactic acid does not*

Modes of ATP Synthesis During Exercise



Oxygen Debt

- Heavy breathing continues after strenuous exercise
  - excess post-exercise oxygen consumption (EPOC) – the difference between the resting rate of oxygen consumption and the elevated rate following exercise.
  - typically about 11 liters extra is needed after strenuous exercise
  - repaying the oxygen debt

Oxygen Debt

- Oxygen need in excess of current muscle activity for the following reasons:
  - **replace oxygen reserves** depleted in the first minute of exercise
    - oxygen bound to myoglobin and blood hemoglobin
    - oxygen dissolved in blood plasma and other extracellular fluid
    - oxygen in the air in the lungs
  - **replenishing the phosphagen system**
    - synthesizing ATP and using some of it to donate the phosphate groups back to creatine until <u>resting levels of ATP and CP are restored</u>

Oxygen Debt

- Oxygen need in excess of current muscle activity for the following reasons:
  - **oxidizing lactic acid**
    - 80% of lactic acid produced by muscles enter bloodstream
    - reconverted to pyruvic acid in the kidneys, cardiac muscle, and especially the liver
    - liver converts most of the pyruvic acid back to glucose to replenish the glycogen stores of the muscle.
  - **serving the elevated metabolic rate**
    - occurs while the body temperature remains elevated by exercise and consumes more oxygen

Endurance

- endurance – the ability to maintain high-intensity exercise for more than 4 to 5 minutes
  - determined in large part by one's maximum oxygen uptake (VO_2max)
  - maximum oxygen uptake – the point at which the rate of oxygen consumption reaches a plateau and does not increase further with an added workload
    - proportional to body size
    - peaks at around age 20
    - usually greater in males than females
    - <u>can be twice as great in trained endurance athletes as in untrained person</u>
      - results in twice the ATP production

Muscle Fatigue

- Characterized by progressive weakness and loss of contractility from prolonged use of the muscles
  - To experience muscle fatigue try this:
    - repeated squeezing of rubber ball
    - rapidly opening and closing your hand as if making a fist (one minute)
    - holding text book out level to the floor

Fatigue

- Causes of muscle fatigue
  - ATP synthesis declines as glycogen is consumed
  - ATP shortage slows down the Na^+ - K^+ pumps
    - compromises their ability to maintain the resting membrane potential and excitability of the muscle fibers
  - Lactic acid lowers pH of sarcoplasm
    - inhibits enzymes involved in contraction, ATP synthesis, and other aspects of muscle function

Fatigue

- Causes of muscle fatigue (cont)
  - release of K^+ with each action potential causes the accumulation of extracellular K^+ /// hyperpolarizes the cell and makes the muscle fiber less excitable
  - motor nerve fibers use up their Ach /// less capable of stimulating muscle fibers – junctional fatigue
  - central nervous system, where all motor commands originate, fatigues by unknown processes, so there is less signal output to the skeletal muscles

Beating Muscle Fatigue

- Taking **oral creatine** increases level of creatine phosphate in muscle tissue and increases speed of ATP regeneration
  - useful in burst type exercises – weight-lifting
  - risks are not well known
    - muscle cramping, electrolyte imbalances, dehydration, water retention, stroke
    - kidney disease from overloading kidney with metabolite creatinine

Beating Muscle Fatigue

- carbohydrate loading – a form of dietary regimen
  - Loads maximum amount of glycogen into muscle cells
  - extra glycogen is hydrophilic and adds 2.7 g water/ g glycogen
    - athletes feel sense of heaviness outweighs benefits of extra available glycogen