Life requires energy. A cell uses energy to build and maintain its structure, transport materials, manufacture products, move, grow, and reproduce. This energy ultimately comes from the sun. The figure shows that in these energy conversions some energy is lost as heat. In photosynthesis the energy of sunlight is used to rearrange the atoms of CO2 and H2O to produce glucose and O2. In cellular respiration, O2 consumed as glucose is broken down to CO2 and H2O: the cell captures the energy released in ATP.
Respiration refers to an exchange of gases: An organism obtains O2 from its environment and releases CO2 as a waste product. Cellular respiration is the aerobic harvesting of energy from food molecules by cells. As the runner in picture breathes in air, her lungs take up O2 and pass it to her bloodstream. The bloodstream carries the O2 to her muscle. Mitochondria in the muscle cells use the O2 in cellular respiration, harvesting energy from glucose and other organic molecules to generate ATP, which the cells then use to contract.
Generating ATP for cellular work is the fundamental function of cellular respiration. The balanced chemical equation summarizes cellular respiration as carried out by cells that use O2 in harvesting energy from glucose. The equation tells us that atoms of the starting (reactants) molecules glucose and O2 regroup to form the products CO2 and H2O. Cellular respiration can produce up to 38 ATP molecules for each glucose molecule.
The human body uses energy from ATP for all its activities

• Kilocalories (kcal)- An Energy unit, the quantity of heat required to raise the temperature of 1 kilogram (kg) of water by 1 degree Celsius.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Kcal Consumed per Hour by a 67.5-kg (150-lb) Person*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Running (7 min/mi)</td>
<td>979</td>
</tr>
<tr>
<td>Dancing (fast)</td>
<td>510</td>
</tr>
<tr>
<td>Bicycling (10 mph)</td>
<td>490</td>
</tr>
<tr>
<td>Swimming (2 mph)</td>
<td>408</td>
</tr>
<tr>
<td>Walking (3 mph)</td>
<td>245</td>
</tr>
<tr>
<td>Dancing (slow)</td>
<td>204</td>
</tr>
<tr>
<td>Sitting (writing)</td>
<td>28</td>
</tr>
</tbody>
</table>

*Not including kcal needed for body maintenance
The energy available to a cell is contained in the arrangement of electrons in the chemical bonds that hold an organic molecule like glucose. During cellular respiration, electrons are transferred to oxygen as the carbon-hydrogen bonds of glucose are broken and the hydrogen-oxygen bonds of water form. The movement of electrons from one molecule to another is an oxidation-reduction reaction, or REDOX REACTION. In a redox reaction, the loss of electrons from one substance is called OXIDATION, and the addition of electrons to another substance is called REDUCTION. A molecule is said to become oxidized when it looses one or more electrons and reduced when it gains one or more electrons.
Two key players in the process of oxidizing glucose are an enzyme, called DEHYDROGENASE and a coenzyme called NAD+. NAD+ (nicotinamide adenine dinucleotide) is an organic molecule that cells make from the vitamin niacin and use to shuttle electrons in redox reactions.
Cellular respiration consists of a sequence of steps that can be divided into three main stages.

STAGE 1: GLYCOLYSIS- occurs in the cytoplasmic fluid of the cell, that is, outside the organelles. Glycolysis begins respiration by breaking glucose into two molecules of a three-carbon compound called Pyruvate.

STAGE 2: CITRIC ACID CYCLE- takes place within the mitochondria. It completes the breakdown of glucose by decomposing a derivative of pyruvate to carbon dioxide. The main function of glycolysis and the citric acid cycle is to supply the third stage of respiration with electrons.

STAGE 3: OXIDATIVE PHOSPHORYLATION involves the electron transport chain and a process known as chemiosmosis. NADH and related electron carrier, FADH2, shuttle electrons to the electron transport chain embedded in the inner mitochondrial membrane. Most the ATP produced by cellular respiration is generated by oxidative phosphorylation, which uses the energy released by the downhill fall of electrons from NADH and FADH2 to O2 to phosphorylate ADP.

As the electron transport chain passes electrons down the energy staircase, it also pumps hydrogen ions (H+) across the inner mitochondrial membrane into the narrow intermembrane space. The result is a concentration gradient of H+ across the membrane. In CHEMIOSMOSIS, the potential energy of this concentration gradient is used to make ATP. The concentration gradient drives the diffusion of H+ through ATP SYNTHASES, protein complexes built into the inner membrane that synthesize ATP.
GLYCOLYSIS means the splitting of sugar. GLYCOLYSIS begins with a single molecule of glucose and concludes with two molecules of pyruvate. In SUBSTRATE-LEVEL PHOSPHORYLATION an enzyme transfers a phosphate group from a substrate molecule directly to ADP, forming ATP. This process produces a small amount of ATP in both glycolysis and the citric acid cycle.
The compounds that form between the initial reactant, glucose, and the final product, pyruvate, are known as INTERMEDIATES. The energy investment phase, actually consume energy. In this phase, ATP is used to energize a glucose molecule, which is then split into two small sugars that are now primed to release energy.
The energy payoff phase, yield energy for the cell. In this phase, two NADH molecules are produced for each initial glucose molecule, and four ATP molecules are generated. Since the first phase uses two molecules of ATP, the net gain to the cell is two ATP molecules for each glucose molecules that enters glycolysis. These two ATP molecules from glycolysis account for only 5% of the energy that a cell can harvest from a glucose molecule.
As pyruvate forms at the end of glycolysis, it is transported from the cytoplasm into a mitochondrion, the site of the citric acid cycle. Pyruvate itself does not enter the citric acid cycle. A large, multi-enzyme catalyzes three reactions.

1.) A carboxyl group (COO) is removed from pyruvate and given off as a molecule of CO₂ (this is the first step in which CO₂ is produced)
2.) The two-carbon compound remaining is oxidized while a molecule of NAD is reduced to NADH
3.) A compound called COENZYME A, derived from B vitamin, joins with the two-carbon group to form a molecule called acetyl coenzyme A.

Acetyl coenzyme A, abbreviated ACETYL CoA, is a high-energy fuel molecule for the citric acid cycle. For each molecule of glucose that entered glycolysis, two molecules of acetyl CoA are produced and enter the citric acid cycle.
The citric acid cycle is often called the Kreb’s cycle in honor of Hans Krebs, the German–British researcher who worked out much of this cyclic phase of cellular respiration. Only the two-carbon acetyl part of the acetyl CoA molecule actually participates in the citric acid cycle. Coenzyme A helps the acetyl group enter the cycle and then splits off and is recycled. The acetyl group joins a four-carbon molecule. The resulting six-carbon molecule is processed through a series of redox reactions, two carbon atoms are removed as CO2, and the four-carbon molecule is regenerated. The six-carbon compound first formed in the cycle is citrate, the ionized form of citric acid. Each turn of the cycle makes one ATP molecule by substrate-level phosphorylation. It also produces four other energy-rich molecules: Three NADH molecules and one molecules of the electron carrier, FADH2.
The final stage of cellular respiration is oxidative phosphorylation, which involves the electron transport chain and chemiosmosis. The gold arrow traces the path of electron flow from the shuttle molecules NADH and FADH2 through the electron transport chain to oxygen, the final electron acceptor. Each oxygen atom accepts two electrons from the chain and picks up two hydrogen ions from the surrounding solution to form H2O, one of the final products of cellular respiration. Three of the protein complexes use the energy released from these electron transfers to actively transport H+ across the membrane, from where H+ is less concentrated to where it is more concentrated. The resulting H+ gradient stores potential energy. The ATP synthases built into the inner mitochondrial membrane act like miniature turbines. The hydrogen ions tend to be driven across the membrane by the energy of their concentration gradient. However, the membrane is not permeable to hydrogen ions, and they can only cross through a channel in the ATP synthase. Hydrogen ions rush back “downhill” through an ATP synthase, spinning a component of the complex. The rotation activates catalytic sites on the synthase that attach phosphate groups to ADP molecules to generate ATP.
Three different categories of poisons obstruct cellular respiration. A substance called ROTENONE, binds tightly with one of the electron carrier molecules in the first protein complex, preventing electrons from passing to the next carrier molecule. Two other electron transport blockers, CYANIDE and CARBON MONOXIDE, bind with an electron carrier in the fourth protein complex. Here they block the passage of electrons to oxygen. A second type of respiratory poison inhibits ATP synthase. The antibiotic OLIGOMYCIN locks the passage of H+ through the channel in ATP synthase. A third kind of poison, collectively called UNCOUPLERS, makes the membrane of the mitochondrion leaky to hydrogen ions. When DNP is present, all steps of cellular respiration except chemiosmosis continue to run, consuming fuel molecules, even though almost all the energy is lost as heat.
Glycolysis, occurring in the cytoplasmic fluid, and the citric acid cycle, occurring in the mitochondrial matrix, contribute a net total of 4 ATP per glucose molecule by substrate-level phosphorylation. The cells harvest much more energy than this from the carrier molecules NADH and FADH2, which are produced by glycolysis, the grooming of pyruvate, and the citric acid cycle. The energy of the electrons they carry is used to make an estimated 34 molecules of ATP using the electron transport chain and chemiosmosis in oxidative phosphorylation. NADH= 3 ATP molecules. Another assumption is that FADH2= 2 ATP molecules. The net yield of ATP molecules per glucose molecule has a theoretical maximum of about 38.
Fermentation provides an anaerobic path for recycling NADH back to NAD+

LACTIC ACID FERMENTATION:
You can see that NADH is oxidized to NAD+ as pyruvate is reduced to lactate. The lactate that builds up in muscle cells during strenuous exercise is carried in the blood to the liver, where it is converted back to pyruvate.

ALCOHOL FERMENTATION:
Yeasts are single-celled fungi that normally use aerobic respiration to process their food. But they are also able to survive in anaerobic environments. Yeast and certain bacteria recycle their NADH back to NAD+ while converting pyruvate to CO2 and ETHANOL.

OBLIGATE ANAEROBES - Require anaerobic conditions and are poisoned by oxygen.
FACULATIVE ANAEROBE - can make ATP either by fermentation or by oxidative phosphorylation, depending on whether O2 is available.
Glycolysis evolved early in the history of life on earth

• Glycolysis is the universal energy-harvesting process of life

• Significant levels of O2 did not accumulate in the atmosphere until about 2.7 billions years ago

• For almost a billion years, prokaryotes must have generated ATP exclusively from glycolysis, because it does not require O2
Most macromolecules must be digested (hydrolyzed) into their components to be harvested to make energy.
Not all food molecules are destined to be oxidized as fuel for making ATP. Food also provides the raw materials a cell uses for biosynthesis - the production of organic molecules using energy-requiring metabolic pathways.