

Supplemental Material

CBE—Life Sciences Education

Wernecke *et al.*

Enhancing Conceptual Knowledge of Energy in Biology with Incorrect Representations

Supplemental Material

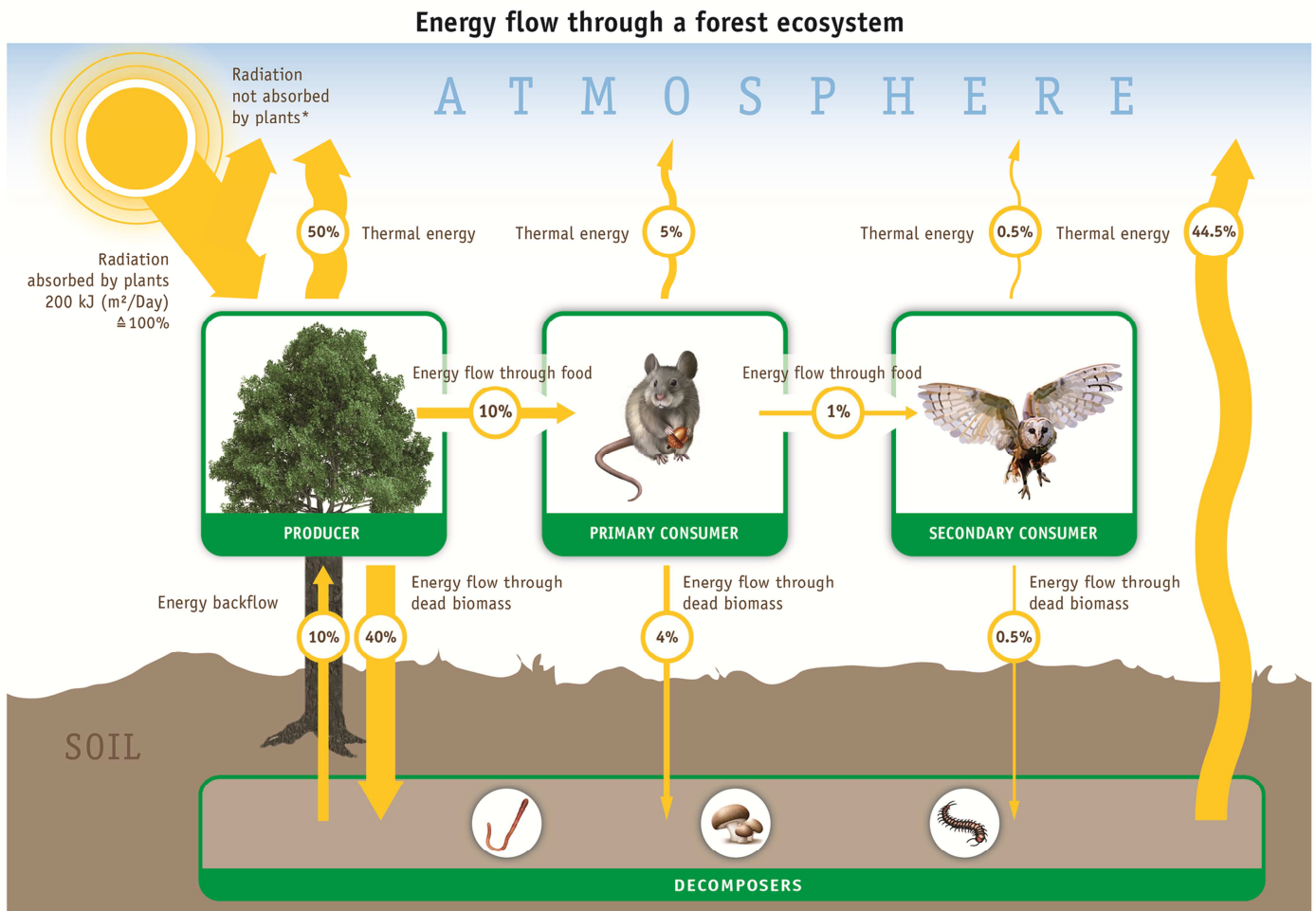
Part 1: Learning Material

Part 2: Energy Test

Part 3: Presentation

Part 1: Learning Material

1.1 Learning material provided to Group 1



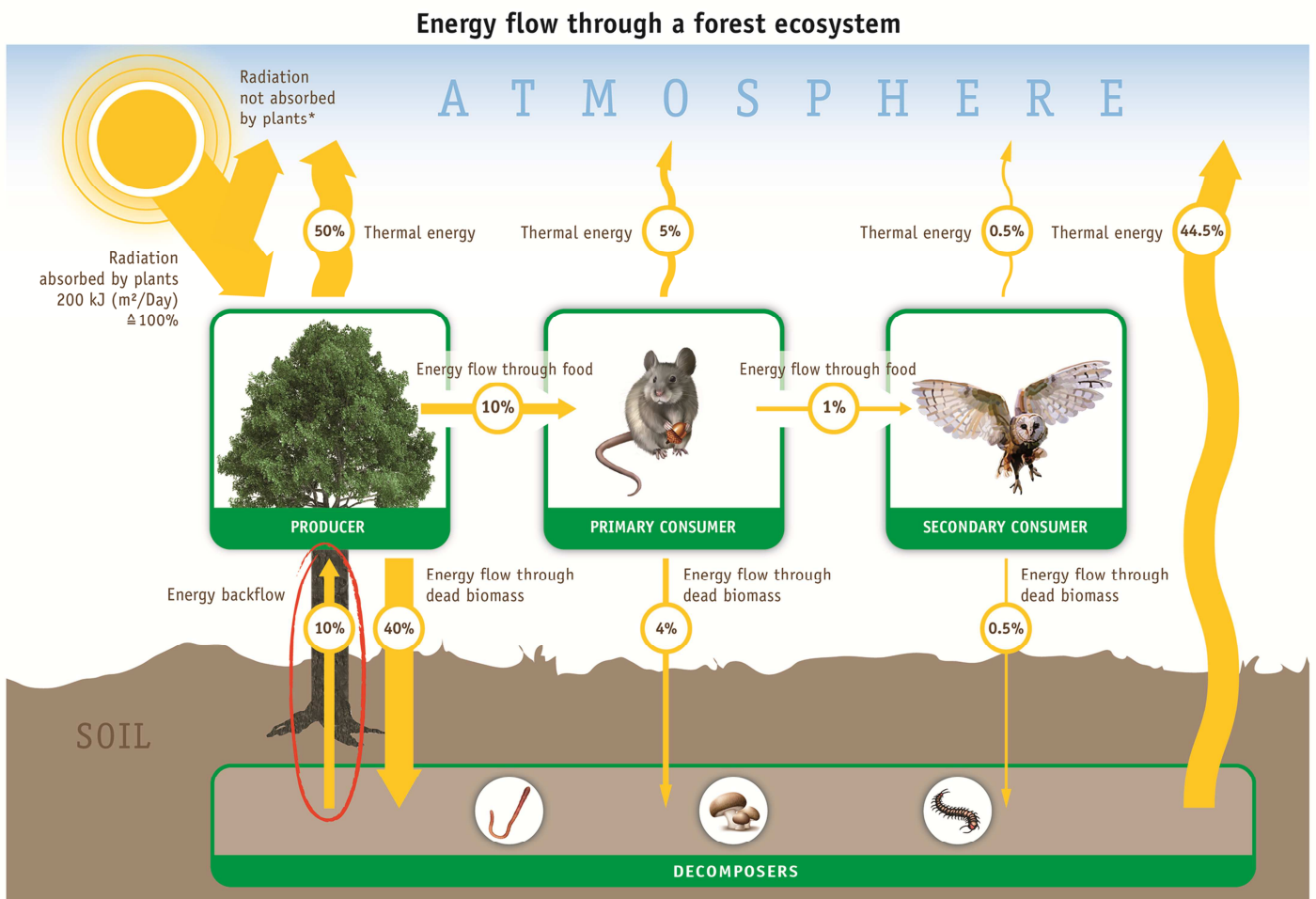
Drawing (including the width of arrows) is not true to scale.

*e.g. radiation reflected by the earth's surface

Anna found this diagram in the journal of her environmental organization. She is not sure whether she understands it correctly. Therefore, she shows it to her biology teacher and asks her for help. The teacher discovers an error in the diagram.

1. What error has Anna's teacher found? Encircle the error.
2. Explain the energy flow through the forest ecosystem on the basis of the diagram. Give reasons why you marked the feature as incorrect. Mention typical characteristics of energy flow that can be derived from the diagram and also apply to energy flows of other ecosystems.

1.2 Learning material provided to Group 2



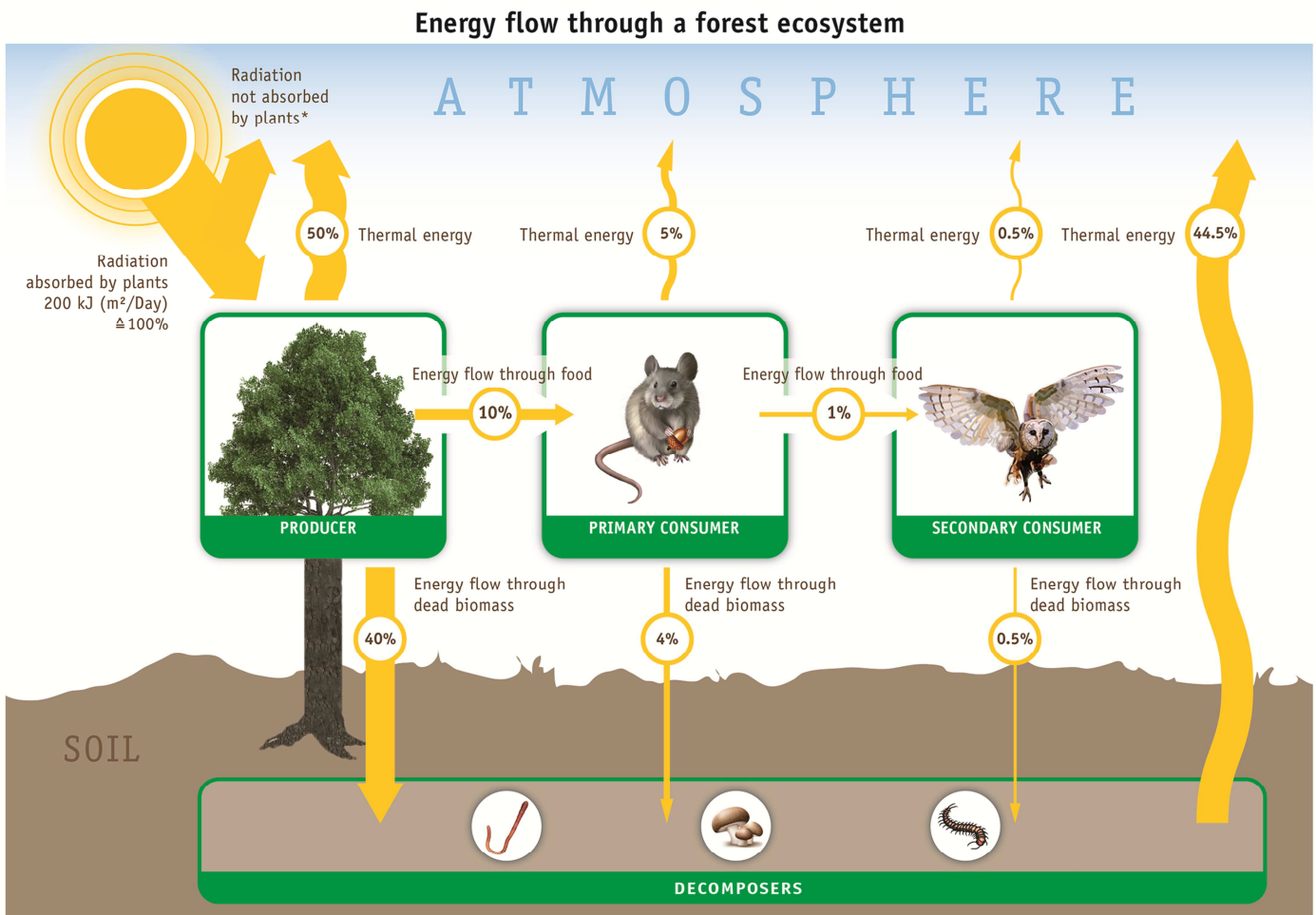
Drawing (including the width of arrows) is not true to scale.

*e.g. radiation reflected by the earth's surface

Anna found this diagram in the journal of her environmental organization. She is not sure whether she understands it correctly. Therefore, she shows it to her biology teacher and asks her for help. The teacher discovers an error in the diagram and encircles it.

Task: Explain the energy flow through the forest ecosystem on the basis of the diagram. Give reasons why the teacher marked the spot as incorrect. Mention typical characteristics of energy flow that can be derived from the diagram and also apply to energy flows of other ecosystems.

1.3 Learning material provided to Group 3



Drawing (including the width of arrows) is not true to scale.

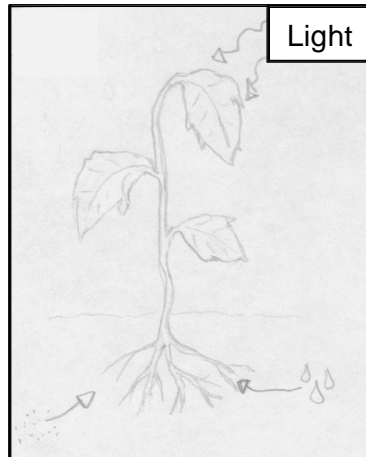
*e.g. radiation reflected by the earth's surface

Anna found this diagram in the journal of her environmental organization. She is not sure whether she understands it correctly. Therefore, she shows it to her biology teacher and asks her for help.

Task: Explain the energy flow through the forest ecosystem on the basis of the diagram. Mention typical characteristics of energy flow that can be derived from the diagram and also apply to energy flows of other ecosystems.

Part 2: Energy Test

Task 1

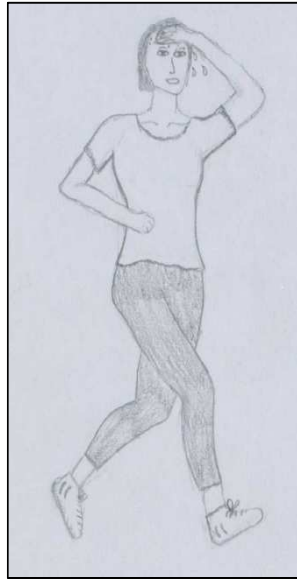


Plants produce sugar for their growth from carbon dioxide (CO₂) with the help of sunlight. The amount of sugar that is produced depends on several factors.

Match each of the four points to the correct energy form.

	Energy form			
	Thermal energy	Light energy	Kinetic energy	Chemical energy
<div style="border: 1px solid black; padding: 5px; width: fit-content; margin: auto;"> In each line, one energy form is correct! </div>				
Sunlight				
Temperature of the environment				
Wind speed (in a storm, leaves rarely directly face the sun)				
Sugar produced for plant growth with the help of sunlight				

Task 2



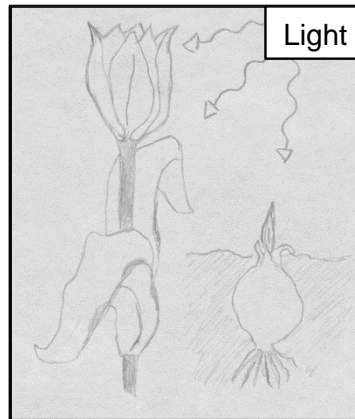
People sweat when they move a lot. Sweating helps to keep the body temperature constant.

Select the statements that correctly describe the relation between increasing movement and the degradation of energy into heat!

2 answers
are correct!

- Through increased movement, additional chemical energy is converted into heat. This additional energy has to be released into the environment because a build-up of heat would harm the body.
- During exercise, friction in the body increases. Through combustion of chemical energy in the body, additional heat is released. As the environment is cooler than the body, heat is released to the environment, where it is degraded. As a form of 'insulation', sweat works as a counter measure.
- Through evaporation of sweat, the skin is cooled. This way, excessive heat is released. However, the skin can transform heat back into chemical energy. Thereby, degraded energy is 're-valued'.
- The skin is cooled down by the evaporation of sweat. In this process, excessive heat is released into the environment. Thereby, the body is protected from overheating. However, the energy is 'degraded', because the body cannot transform heat any further.

Task 3



For its growth, a flower can use the sun's light energy, but also the energy stored in its flower bulb.

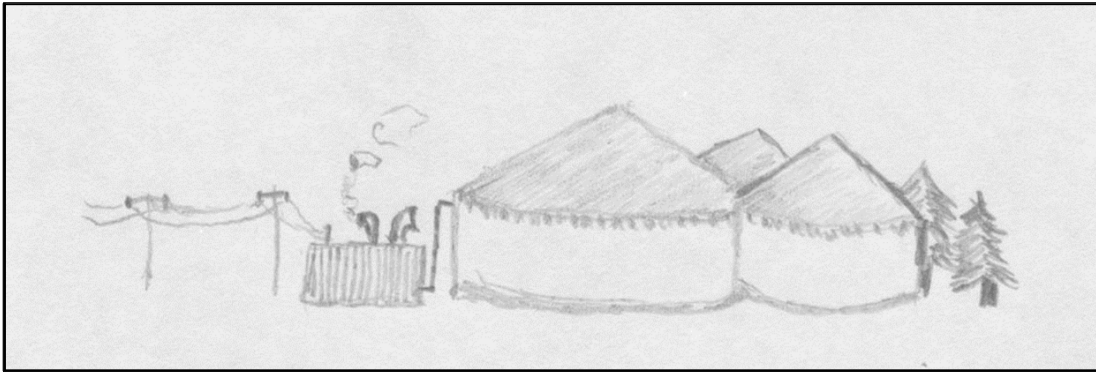
For the following three steps, select ...

(A) which pair of energy forms is involved, and ...

(B) how the energy is passed on!

Steps	(A) Energy forms			(B) How energy is passed on	
	Light energy → chemical energy	Chemical energy → chemical energy	Light energy → thermal energy	Transfer , because the energy form remains the same	Transformation , because the energy form changes
(1) With the help of sunlight, the flower's leaves build up sugar from carbon dioxide.					
(2) Sugar, that was stored in the flower bud, is broken down. Its energy is used for the growth of the plant.					
(3) As the sugar is built up, heat is released, too.					

Task 4



In the last years, biogas plants (see drawing) have been widely established as small, decentralized power stations to provide a renewable energy source. Assume that a biogas plant is supplied with 2.000.000 kJ (kiloJoules; \approx 480.000 kcal, kilocalories) of chemical energy in plant material ('biomass').

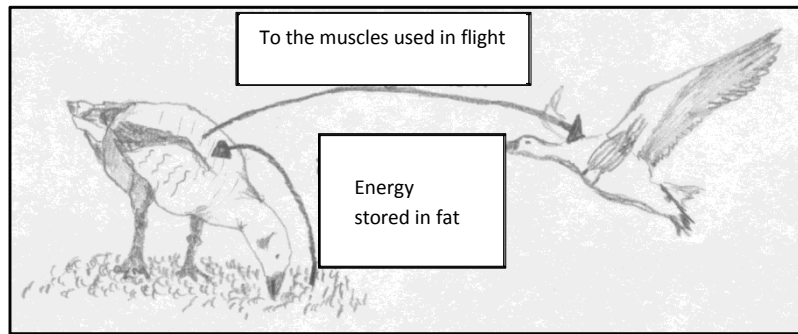
Select the statements that correctly describe how the amount of energy supplied to the biogas plant relates to the amount of energy transformed from it in the plant!

2 answers

are correct!

- Micro-organisms decompose biomass. The hereby released gas (methane) is combusted by an engine. The chemical energy of the gas is transformed into thermal and kinetic energy. A generator then transforms the kinetic energy into electric energy.
- Micro-organisms digest the chemical energy of the plant material. They thereby release a gas from which electric energy is produced. While the chemical energy is lost in this process, electric energy can be created.
- In all transformations in the plant, heat is released. The heat is largely emitted into the environment and then stays unused. In sum, the emitted thermal energy, the electric energy and the chemical energy of residue biomass represent the initial 2.000.000 kJ. The energy is conserved.
- In combustion, the supplied chemical energy is lost, as it is consumed. The emitted heat contains no energy. The energy leaving the plant (as electric power and waste) contains much less energy than the initially supplied energy of 2.000.000 kJ.

Task 5



Before they go on their annual migration, birds put on a lot of weight and thereby store a lot of energy in fat stores. To generate movement, energy is passed on from the fat store to the muscles.

For the following three steps, select ...

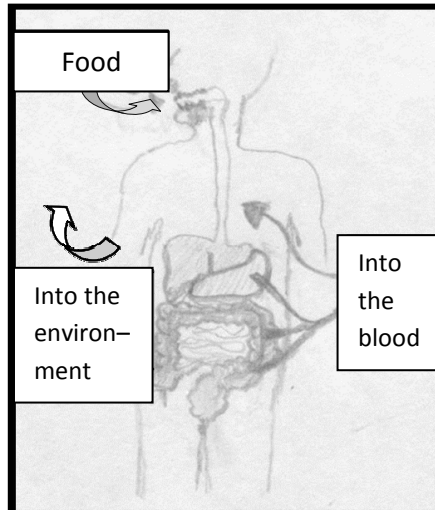
(A) which pair of energy forms is involved, and ...

(B) how the energy is passed on!

Steps	(A) Pair of energy forms			(B) How energy is passed on.	
	Chemical energy → chemical energy	Chemical energy → kinetic energy	Kinetic energy → thermal energy	Transfer, because the energy form stays the same	Transformation, because the energy form changes.
(1) Chemical energy from the fat store is transported to the muscle and then handed over to the body's energy currency.					
(2) The 'energy currency' causes the muscle to contract. Thereby, the muscle moves.					
(3) The movement also causes friction. Therefore, energy is also passed on as heat.					

For each of the steps, tick **one box for (A)** AND **one box for B.**

Task 6



A person takes up energy from the environment and transforms it in the body. A part of the energy is released back into the environment, another part remains in the body.

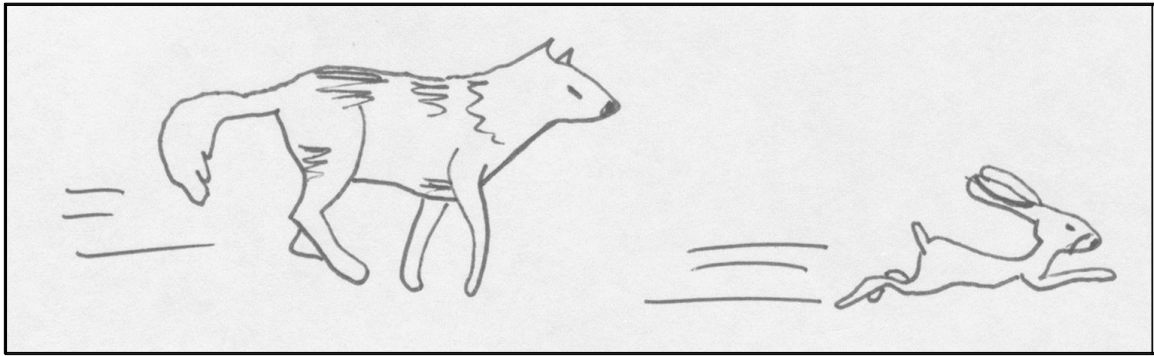
(A) In the following three steps, select if the energy is taken up by the body/stored in it, OR, if it's released back into the environment.

In part (A), chose one option for each of the three cases . In part (B), chose one option .	Energy taken up/stored in the body	Energy released by the body into the environment
1) Chemical energy from food	<input type="radio"/>	<input type="radio"/>
2) Chemical energy in growing body parts	<input type="radio"/>	<input type="radio"/>
3) Energy transformed into heat in the body	<input type="radio"/>	<input type="radio"/>

(B) Select the correct relation of the given amounts of energy.

The amount of energy taken up is ...	<input type="radio"/> ... smaller than ... <input type="radio"/> ... larger than ... <input type="radio"/> ... equal to the amount of energy released into the environment AND the energy stored in the body.
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Task 7



Two wolves hunt. Wolf number 1 is hunting in northern Canada, where it's very cold. After 10 hours of hunting, he catches one fat hare. Wolf 2 is hunting for one hour in a summer forest and catches a little partridge.

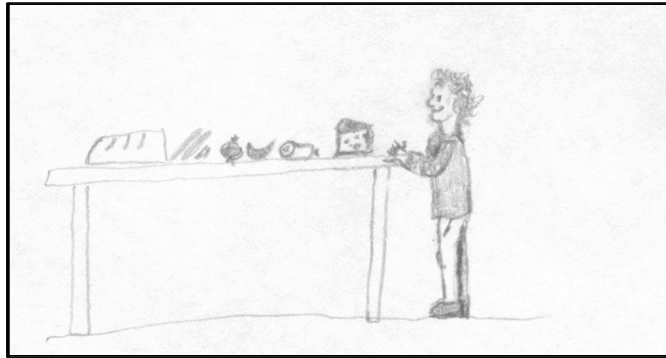
Select the options that correctly identify what the energy in the wolves' bodies is related to.

2 answers

are correct !

- It is important how much chemical energy from food is stored in the wolf's body. The body does not possess chemical energy without food.
- The chemical energy in the wolf depends on the nature and extent of the stores of chemical energy (fats, sugar, proteins) in foods that are taken up by the wolf with the food.
- The chemical energy in the animals depends on how much chemical energy they give off through excrements and how much energy is transformed in body functions (e.g. movement, body heat) during the hunt.
- It is important how much chemical energy is stored in the digestive tract and in the muscles. There are no stores of energy in other body parts. Therefore, there is substantially more energy stored in wolf 1 than in wolf 2.

Task 8



A growing person transforms energy stores from food or from body (fat) for various life processes.

Select, where you can rediscover the energy after the transformation.

2 answers
are correct!

- In new grown body structures, in the person's movement and in undigested parts of the food
- Energy is almost completely stored in new grown body mass (weight). The rest is heat and remains in the body.
- In the heat of the body and the environment
- In the electric currents of nerves which control the body functions
- In heat stores, which the body uses to generate movement

Tick one answer each for the following eight questions!

Task 9

What is the original energy source for all of the food chains in a forest?

- green plants
- consumers
- decomposers
- sunlight
- soil nutrients

Task 10

Organisms classified biologically as decomposers

- make their own food through photosynthesis.
- break down organic matter into its simpler components for use by green plants.
- recycle energy from dead matter back into the ecosystem for use by green plants.
- provide oxygen to consumers.
- provide carbon dioxide to consumers.

Task 11

Consider the following food chain: Grass→ cricket→ frog→ snake

Which of the following is true?

- Energy for the food chain comes from the soil.
- There is more energy available to frogs in the form of crickets than is available to snakes in the form of frogs.
- All of the energy in crickets that are eaten by frogs is transformed into energy in the form of the frog's flesh.
- Unlike the animal organisms in the food chain, grass does not depend upon an energy source to survive.

Task 12

Which of the following statements concerning food chains is correct?

- The organic matter that is built up in a body contains as much energy as the food contained.
- The biomass increases during the food chain, from producers to consumers of higher stages.
- Food production depends on sunlight finally.
- Especially pollutants that are readily biodegradable are accumulated during the food chain.

Task 13

Which of the following statements concerning ecosystems is correct?

- The whole energy of an ecosystem is gradually transformed to heat energy and emitted into space.
- Organisms living in an ecosystem can transform heat energy to kinetic energy.
- Energy and nutrients are recycled in an internal circle of an ecosystem.
- The thinner earth' crust, the more energy an ecosystem gets out of earth' interior.

Task 14

On what factor depends the energy inflow of most food chains typically?

- how much grass primary consumers eat
- efficiency of matter cycle of the whole ecosystem
- efficiency of producers regarding the conversion of rays of sunlight into chemical energy
- activity of bacteria that fix nitrogen

Task 15

Which of the following statements concerning biomass in a forest ecosystem is correct?

- The biomass of primary and secondary consumers is equal.
- The biomass of producers is smaller than the biomass of primary consumers.
- The biomass of secondary consumers is bigger than the biomass of primary consumers, provided that the diversity of species is bigger.
- The biomass of producers is the biggest.

Task 16

Which of the following statements is correct?

- An ecosystem can absorb matter and energy from the environment and also release matter and energy to the environment.
- An ecosystem can absorb matter, but no energy from the environment and can also release matter, but no energy to the environment.
- An ecosystem can absorb energy, but no matter from the environment and also release energy, but no matter to the environment.
- An ecosystem can absorb and release neither matter nor energy from or to the environment.

Task 17

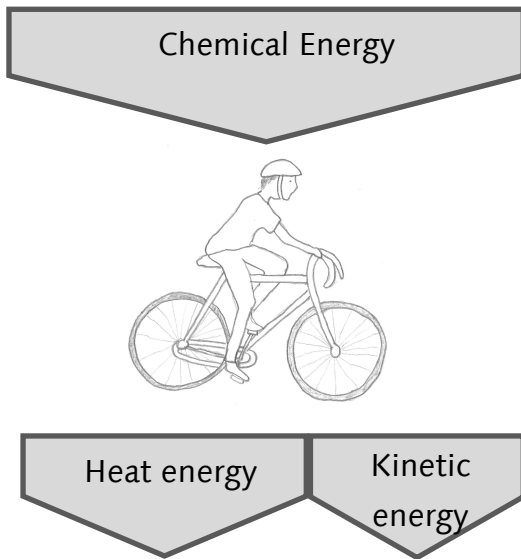


Fig.1: Energy flow diagram of an active person

The diagram in figure 1 shows that the whole chemical energy that the physically active person has ingested before is converted into heat and kinetic energy and given to the environment.

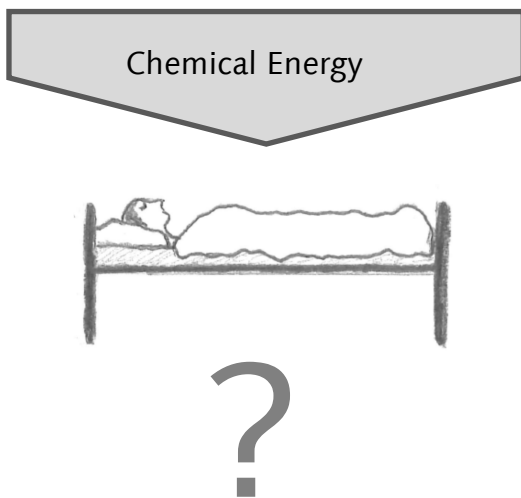


Fig.. 2: Energy flow diagram of a resting person

The diagram in figure 2 is incomplete. It shows a resting person who has ingested as much energy as the active person. Describe in a text what happens to the energy in this case!

Task 18

A raptor with a weight of 1 kg eats about 10 kg mice a year. These 10 kg mice eat, in their turn, about 100 kg of grain. If the raptor fed on grain directly, it would only need to eat 10 kg thereof. Hence, the energy of 90 kg grain could be saved. Try to explain this.

Sources

All items were used in German language.

Task 1 – Task 8: Opitz, S. T. (2016). Students' progressing understanding of the energy concept. An analysis of learning in biological and cross-disciplinary contexts. Dissertation, Christian-Albrechts-University at Kiel, Germany. Retrieved from http://macau.uni-kiel.de/receive/dissertation_diss_00019005 [08.06.2017].

Task 9: Beals, A. M., McNall Krall, R., & Wymer, C. L. (2012). Energy flow through an ecosystem: Conceptions of in-service elementary and middle school teachers. *International Journal of Biology Education*, 2, 1-18. *Item slightly modified.*

Task 10: Beals, A. M., McNall Krall, R., & Wymer, C. L. (2012). Energy flow through an ecosystem: conceptions of in-service elementary and middle school teachers. *International Journal of Biology Education*, 2, 1-18. *Item slightly modified.*

Task 11: Beals, A. M., McNall Krall, R., & Wymer, C. L. (2012). Energy flow through an ecosystem: Conceptions of in-service elementary and middle school teachers. *International Journal of Biology Education*, 2, 1-18. *Item slightly modified.*

Task 12: Hildebrandt, K. (2006). *Die Wirkung systemischer Darstellungsformen und multiperspektivischer Wissensrepräsentationen auf das Verständnis des globalen Kohlenstoffkreislaufs* [The effect of systemic graphic illustrations and multiple knowledge representations on the understanding of the global carbon cycle]. Dissertation, Christian-Albrechts-University at Kiel, Germany. Retrieved from http://eldiss.uni-kiel.de/macau/receive/dissertation_diss_2412 [18.11.2013].

Task 13: constructed by authors

Task 14: Kappei, D., Mühle, C., & Lucius, E. (2009). Klausur 2. Runde an Schulen (Okt./Nov. 2009). [Exam 2. round at schools]. Retrieved from http://wettbewerbe.ipn.uni-kiel.de/ibo/fr_reload.html?erste_runde.html [30.03.2015]. *Item slightly modified.*

Task 15: constructed by authors

Task 16: constructed by authors

Task 17: Beyer, I., Remé, R., & Steinert, C. (2010). *Natura 2. Biologie für Gymnasien* [Natura 2. Biology for academic track schools]. Stuttgart, Germany: Klett. *Item strongly modified.* Note: For legal reasons, we replaced the pictures originally used in this item. The pictures shown here are similar to the ones used before.

Task 18: Burger, J. (2001). *Schülervorstellungen zu "Energie im biologischen Kontext". Ermittlungen, Analysen und Schlussfolgerungen* [Student conceptions concerning energy in biological contexts-research, analysis and conclusions]. Dissertation, University Bielefeld, Germany. Retrieved from <https://pub.uni-bielefeld.de/publication/2305865> [24.06.2016]. *Item slightly modified.*

Part 3: Presentation

Note:

The presentation was translated from German into English.

For legal reasons, we replaced the pictures originally used in this presentation with the pictures used in the energy flow diagram. Before this, the pictures were comparable but not identical.

The photographs shown are the same as those in the original presentation.



Energy Flow through Ecosystems



- Author name & contact -

Ecosystem

=

Set of relationships existing between a community of organisms and their environment.

Organisms are interrelated to one another.

Feeding relationships in an ecosystem

Food chain:



Example:



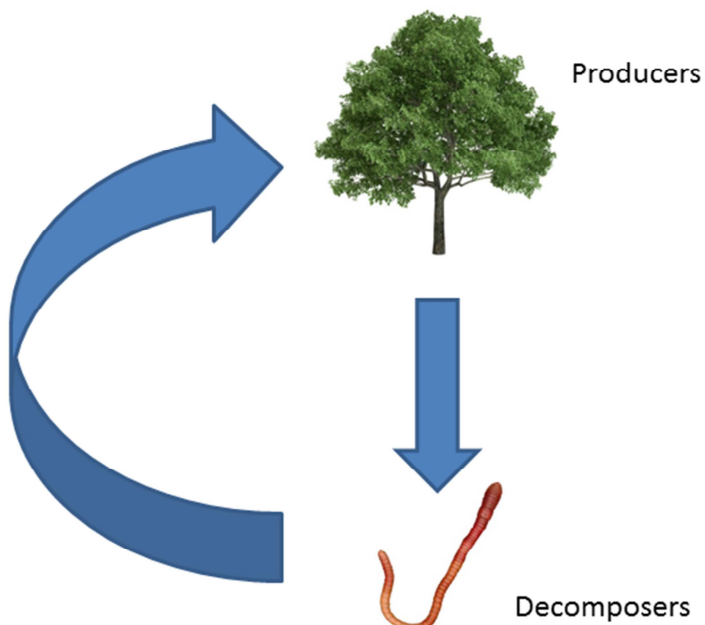
Decomposers (e.g. fungi, earthworms)

- feed on biomass of other organisms, just as consumers.
- break down dead biomass into its inorganic components, such as water, carbon dioxide and mineral salts. These materials can be absorbed by plants.

3

Cycle of matter in an ecosystem

- Certain materials (oxygen, carbon dioxide, mineral salts) are recycled over and over again. Matter circulates in an ecosystem.



4

Energy flow

= energy transfer through an ecosystem

In contrast to matter, energy does not flow in a cycle, but in a “one-way street”.

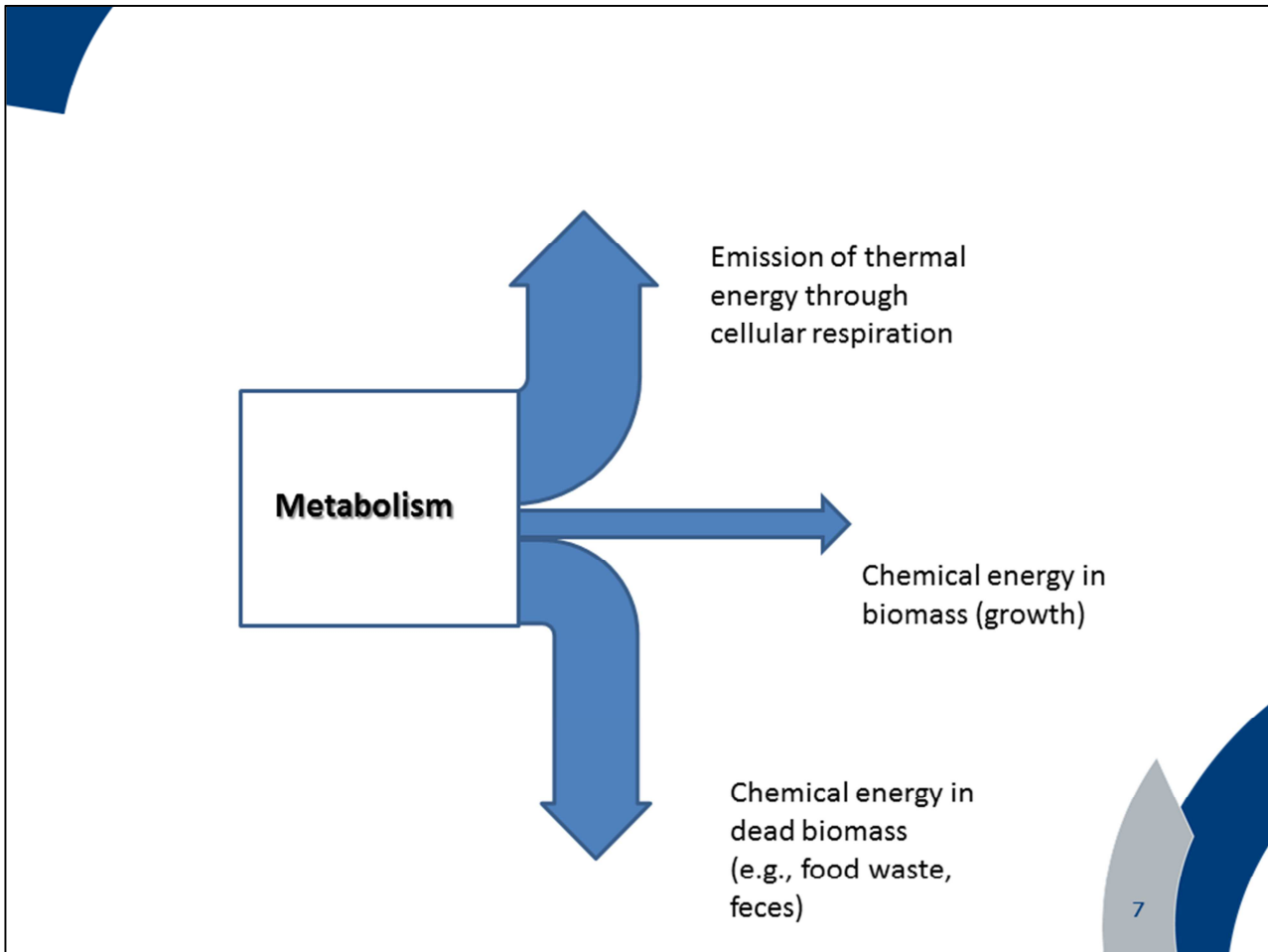
5

Absorption of energy

- Producers (green plants) use radiation energy from the sun for photosynthesis.
- In photosynthesis, energy-rich organic compounds (such as carbohydrates) are synthesized.
- Consumers and decomposers cannot synthesize organic compounds by themselves. They feed on organic compounds of other organisms.



6



Metabolism

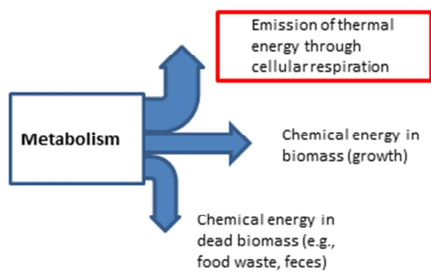
Emission of thermal energy through cellular respiration

Chemical energy in biomass (growth)

Chemical energy in dead biomass (e.g., food waste, feces)

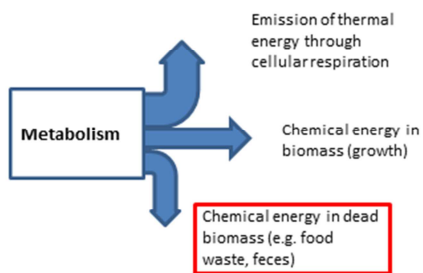
- Metabolic processes run all the time in organisms' cells.
- The processes are always associated with energy conversion, that is, one energy form is transformed into one or more other energy form(s).

8



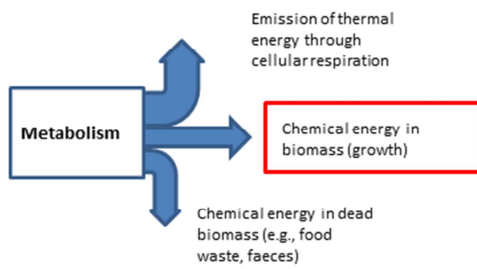
- Every energy transformation generates thermal energy, which is released to the surroundings.
- Organisms cannot convert thermal energy into other energy forms (energy degradation).
- That is why an ecosystem needs a constant energy supply from the sun.

9



- Chemical energy stored in dead biomass feeds decomposers.

10



- Only the energy stored in biomass is available for the next level in the food chain.
- Rule of thumb: From one level in the food chain to the next, only 10% of the energy is transferred.

11



The amount of energy in the universe is always the same, because energy can neither be created nor destroyed (energy conservation).

12