REVISION GUIDE

Back to the set point, or *on to the end*

Feedback

Your blood glucose and your temperature hardly change, whatever you eat or wherever you are. Follow the loops that pull them back, then the loops that run away on purpose: a birth, a feeding baby, a box of ripening bananas.

8 chapters · a dry lab

The interactive guide, with every animation:

biologybybradford.com/guides/ap-biology-unit-4-feedback

Contents

01	Keeping the inside steady	3
02	Every loop has the same parts	5
03	Two hormones, one level	8
04	A broken loop	11
05	Too hot, too cold	14
06	A loop that runs away	17
07	Ripe fruit and full milk	20
08	Back to the set point, or on to the end	23
	Key terms	25
	Dry lab: Glucose tolerance	27
	Check yourself	29
	Answers	30

By the end you can

- [ ] Explain what homeostasis is, and why a variable is held within a normal range around a set point 4.4.A
- [ ] Identify the stimulus, sensor, control center, effector and response in a feedback loop 4.4.A
- [ ] Explain how insulin and glucagon return blood glucose to its set point by negative feedback 4.4.A
- [ ] Predict what happens when part of a loop fails, as in type 1 and type 2 diabetes 4.4.A
- [ ] Explain how sweating, vasodilation, vasoconstriction and shivering hold body temperature steady 4.4.A
- [ ] Explain how positive feedback amplifies a response, in labor, lactation and fruit ripening 4.4.A
- [ ] Compare negative and positive feedback, including negative feedback at the molecular level 4.4.A

Tick each one when you can do it without the book.

01 4.4.A FEEDBACK
Keeping the inside *steady*

Outside you, the weather swings, meals come hours apart, and you run, sleep and sweat. Inside, the fluid that bathes your cells hardly changes. Keeping the internal environment stable while the outside changes is **homeostasis**.

Each controlled variable has a **set point**, the value the body steers toward, and a **normal range** around it. Core body temperature sits near 98.6 °F (37 °C), fasting blood glucose between about 70 and 100 mg/dL, blood pH close to 7.4. The value drifts a little all the time; the body steps in as it starts to leave the range.

Why bother? Cells run on enzymes and membranes that work well only in narrow conditions (Unit 3). Too warm and proteins start to lose their shape; too little glucose and the brain, which burns it without a break, falters. Tap each scale in the figure to read what goes wrong at either end.

Holding steady takes work. A body that did nothing would warm and cool with the room. To respond, it needs a way to detect a change and a way to undo it: a feedback loop, the next chapter.

KEY POINTS

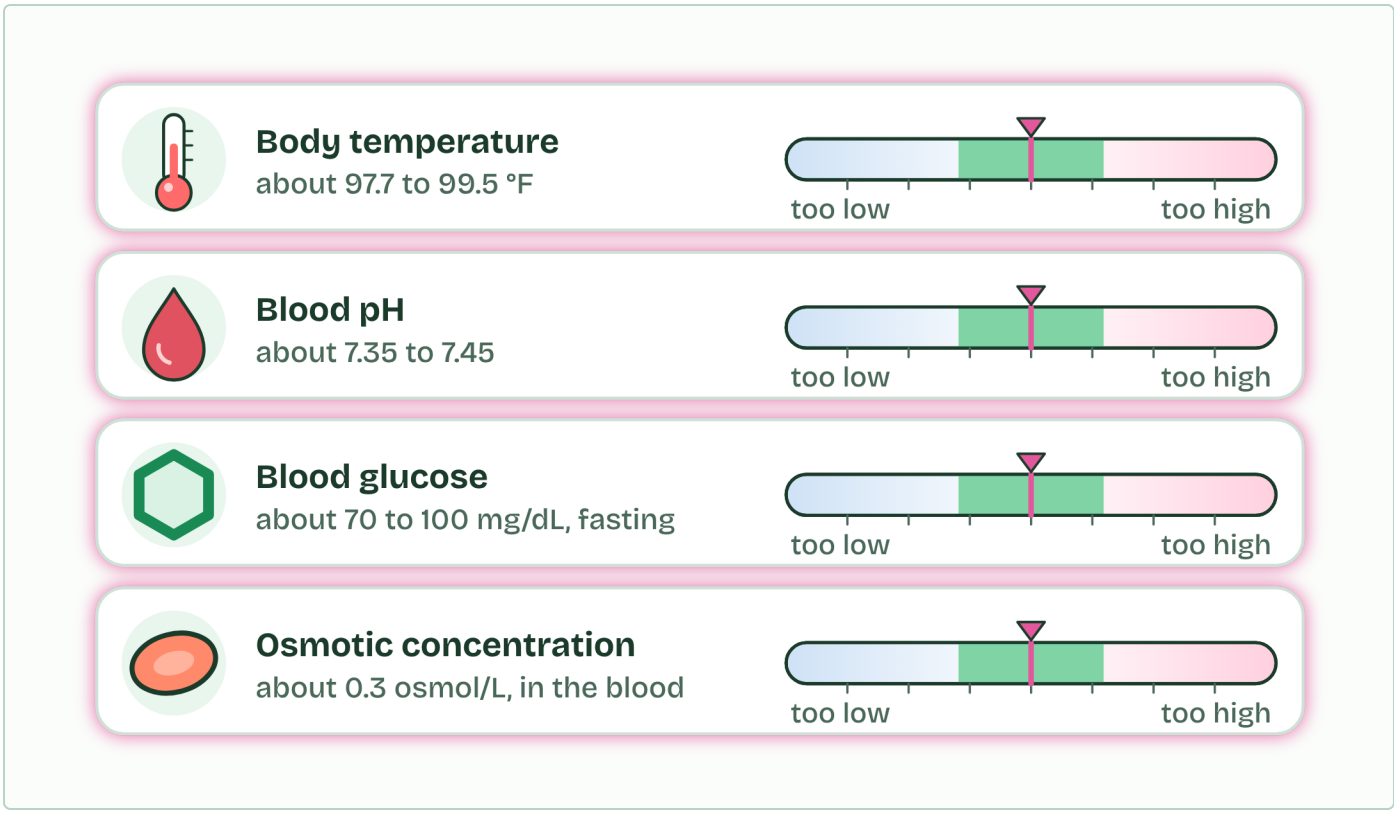
- Homeostasis: a stable internal environment, whatever happens outside.
- Each variable has a set point and a normal range around it.
- Staying in range needs a way to detect a change and a way to reverse it.

KEY TERMS

homeostasis
The maintenance of a stable internal environment, with each controlled variable held within a narrow range, despite changes inside and outside the body.

set point
The value of a controlled variable that a feedback system works to return it to.

normal range
The band of values around a set point within which a variable is allowed to wander without a correction.



Body temperature about 98.6 °F (37 °C). Enzymes work best in a narrow range: colder and reactions slow, hotter and proteins start to lose their shape. The sensors are thermoreceptors, and the control center is the hypothalamus (chapter 5).

Blood glucose about 70 to 100 mg/dL before a meal. The brain depends on a steady supply of glucose. Too much damages blood vessels and draws water out of cells by osmosis (chapters 3 and 4).

Blood pH about 7.4. A change in pH changes the shape of enzymes and other proteins. Carbon dioxide from respiration forms an acid in water, so the rate of breathing helps to hold the pH steady.

Blood osmotic concentration the total concentration of dissolved particles, about 0.3 osmol/L. Too low and cells take in water and swell; too high and they lose water and shrink. The kidneys hold it steady.

WATCH OUT

A set point is a range, not one fixed number. Your temperature drifts by about a degree over a day, lowest in the early morning, and that is normal.

PREDICT

On a winter walk the air drops from 68 °F to 40 °F (20 °C to 4 °C). What happens to the core temperature of a healthy walker?

(A) It falls by close to 28 °F, because heat flows from the body into the cold air until the two match

(B) It stays within about a degree of 98.6 °F, because the body changes how much heat it makes and loses

(C) It rises a few degrees, because the cold makes the body overheat as it works hard against the chill

Decide before you look. Answer on page 30.

02 Every loop has *the same parts*

4.4.A FEEDBACK

A feedback loop is a chain of parts that detects a change and acts on it. The change itself, a rise or a fall away from the set point, is the **stimulus**. A **sensor**, often called a receptor, detects it. A **control center** compares the reading with the set point and sends a signal, by nerve or by hormone. An **effector**, a muscle or a gland, carries out the **response**.

In **negative feedback** the response opposes the stimulus: a rise brings about a fall, and a fall a rise. Once the variable is back at its set point the stimulus has gone, so the signal stops and the loop switches itself off. Push the variable the other way and the same kind of loop pulls it back up from below.

AP questions often hand you a loop and ask what happens when one part fails. Trace it link by link: a part that fails cuts off every link after it, so the effector never acts and the variable is left to drift.

KEY TERMS

stimulus
A change in a controlled variable, away from its set point, that a feedback loop detects.

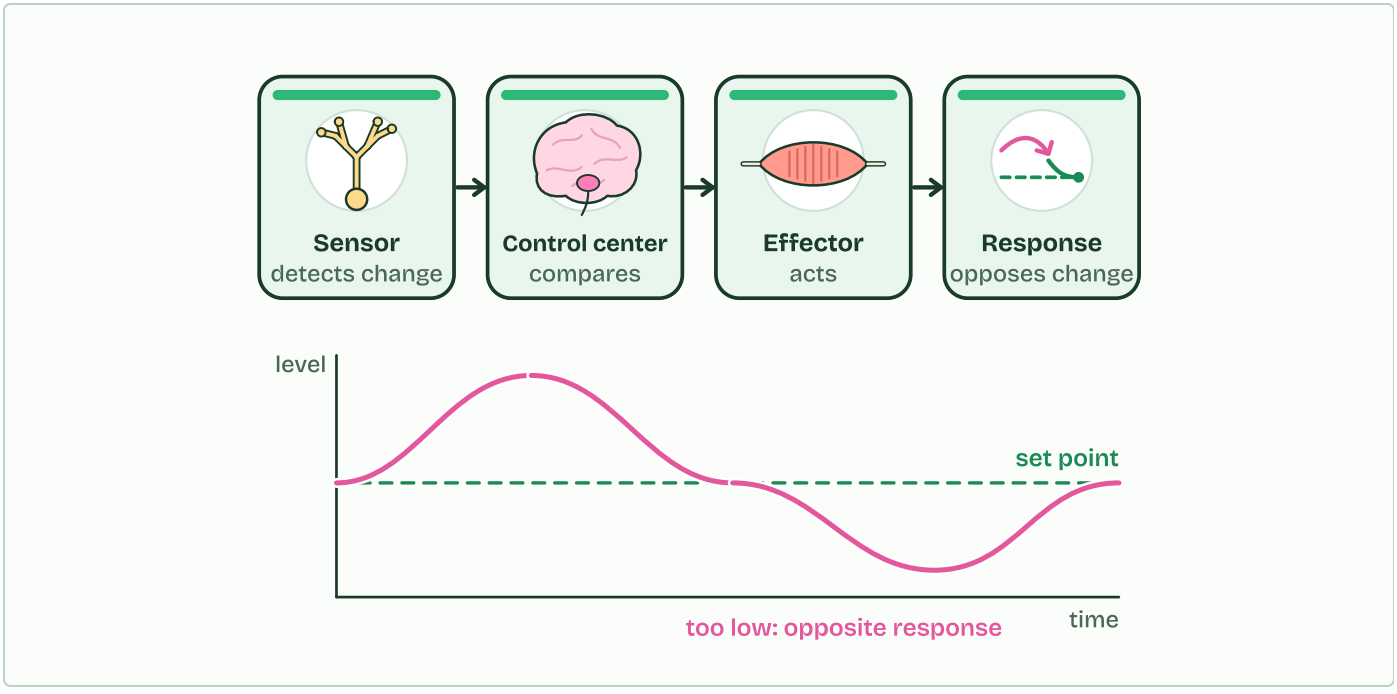
sensor
A cell or organ that detects the stimulus; often called a receptor.

control center
The part of a loop, such as the hypothalamus or the islets of the pancreas, that compares the variable with its set point and sends a signal to the effectors.

effector
A muscle or gland that receives the control center's signal and acts on it.

response
What the effector does, which changes the variable.

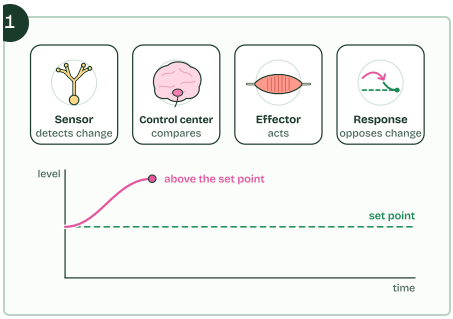
negative feedback
Control in which the response opposes the stimulus, so a perturbed variable is returned to its set point.



STEP BY STEP

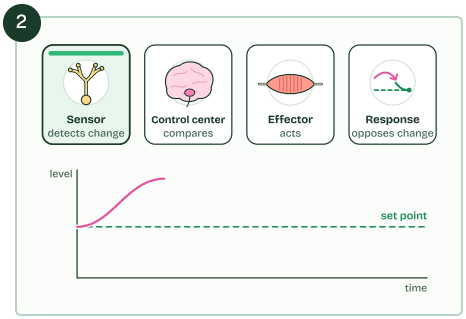
6 STEPS

1



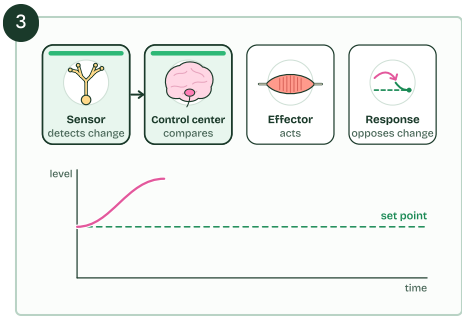
A change, the **stimulus**, pushes the variable above its set point.

2



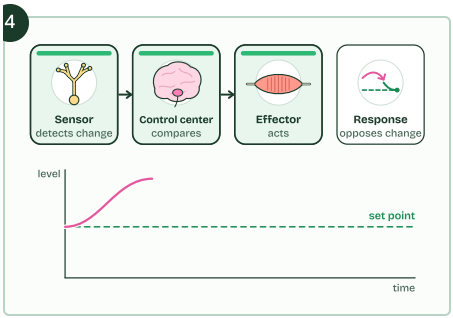
A **sensor**, a receptor, detects the change.

3



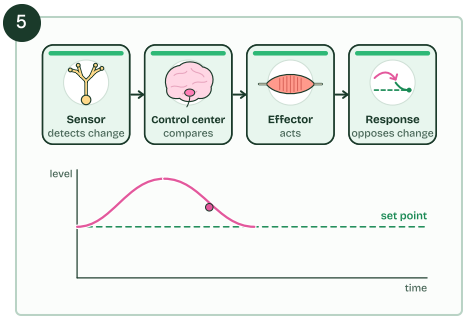
The **control center** compares it with the set point and sends a signal.

4



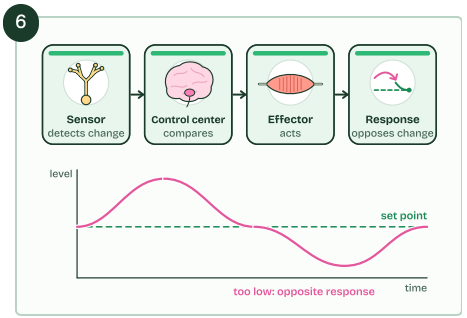
An **effector** acts on the signal.

5



The **response** opposes the change, so the level **falls back** to the set point.

6



If it falls **too low**, the same loop works the other way, and it returns to the set point.

EXAMPLE

A home thermostat. The room cools (the stimulus); the thermometer inside it (the sensor) reads the fall; its circuit (the control center) compares that with the dial and switches the furnace (the effector) on; the room warms (the response). At the dial's setting the furnace goes off again.

REMEMBER IT

The five parts of a loop, in order

S Sly	S Snakes	C Can	E Eat	R Rats
Stimulus the change	**Sensor** detects it	**Control center** compares and signals	**Effector** a muscle or gland acts	**Response** undoes the change

WATCH OUT

Negative feedback does not mean bad feedback. Negative means the response goes the opposite way to the change, and that is exactly what keeps a variable steady.

PREDICT

A drug stops the sensors in a negative feedback loop from detecting anything. The variable then drifts above its set point. What happens next?

(A) The effector works harder than usual, because the control center reads the silence as an emergency

(B) The loop turns itself around and pushes the variable higher still, away from the set point

(C) Nothing corrects it, because no signal reaches the control center, so the effector never acts

Decide before you look. Answer on page 30.

03 Two hormones, *one level*

4.4.A FEEDBACK

Blood glucose is the AP example of negative feedback, and the best studied. Here the sensor and the control center are the same tissue: clusters of cells in the pancreas called islets, which detect the glucose in the blood flowing past them and answer with hormones.

After a meal, glucose absorbed from the gut raises the level. **Beta cells** in the islets release **insulin**. Insulin binds receptors on liver and muscle cells, which take glucose in and join it into **glycogen**, the branched polysaccharide of Unit 1; fat cells take some in too. The level falls back, so the beta cells release less.

Between meals the level falls. **Alpha cells** release **glucagon**, which acts on the liver: liver cells break glycogen down and release glucose into the blood. Muscle has no glucagon receptors, so its glycogen stays for its own use.

Two hormones with opposite effects push the level back from either side. In the film, watch which box of the loop lights at each moment, and how the chart answers.

KEY POINTS

- Glucose high: beta cells release insulin; liver and muscle take glucose in and store it as glycogen.
- Glucose low: alpha cells release glucagon; liver cells break glycogen down and release glucose.
- Two hormones with opposite effects, each switched off as the level returns.

KEY TERMS

beta cells
Cells in the pancreatic islets that release insulin when blood glucose rises.

insulin
A hormone from the beta cells of the pancreas that lowers blood glucose: liver, muscle and fat cells take glucose in, and liver and muscle store it as glycogen.

glycogen
A branched polysaccharide of glucose, stored in liver and muscle cells.

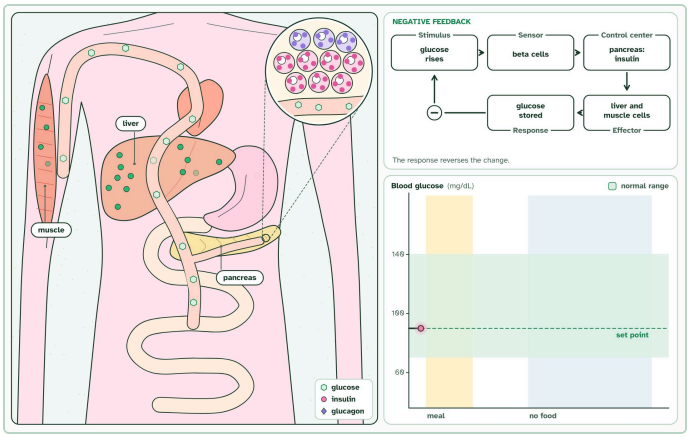
alpha cells
Cells in the pancreatic islets that release glucagon when blood glucose falls.

glucagon
A hormone from the alpha cells of the pancreas that raises blood glucose: liver cells break glycogen down and release glucose into the blood.

ANIMATION · BLOOD GLUCOSE HELD STEADY

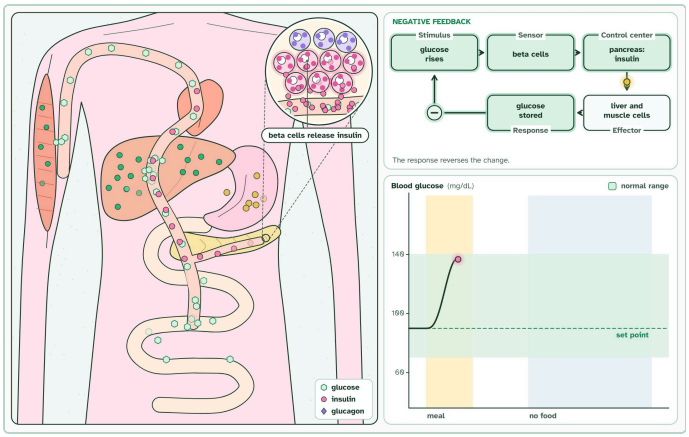
7 MOMENTS

1 GLUCOSE 90 MG/DL



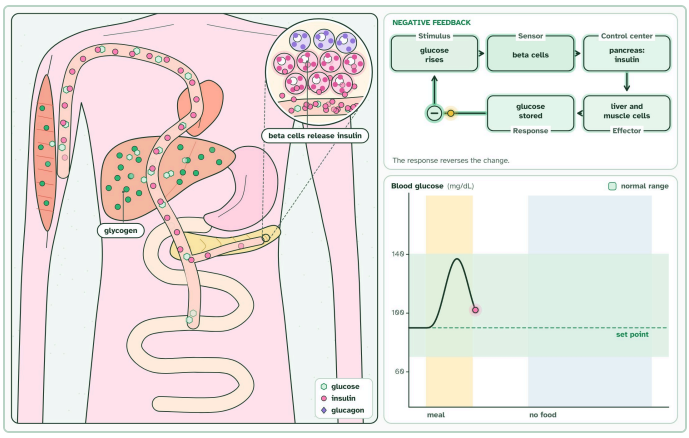
Blood glucose is held close to a **set point**, about 90 mg/dL, inside a narrow normal range. Watch the chart and the loop.

2 GLUCOSE 135 MG/DL



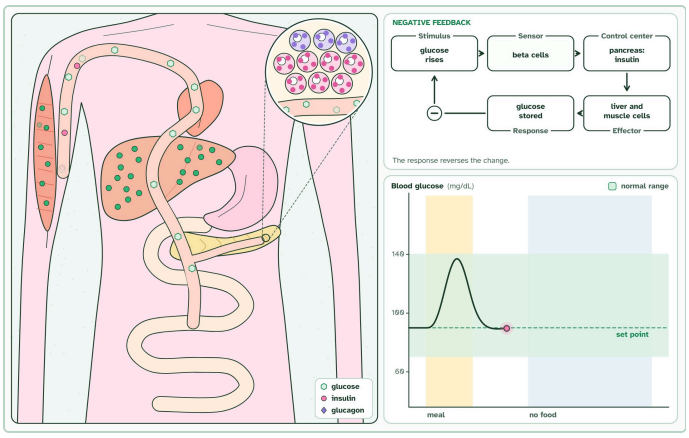
Beta cells in the islets of the pancreas detect the rise and release the hormone **insulin** into the blood.

3 GLUCOSE 100 MG/DL



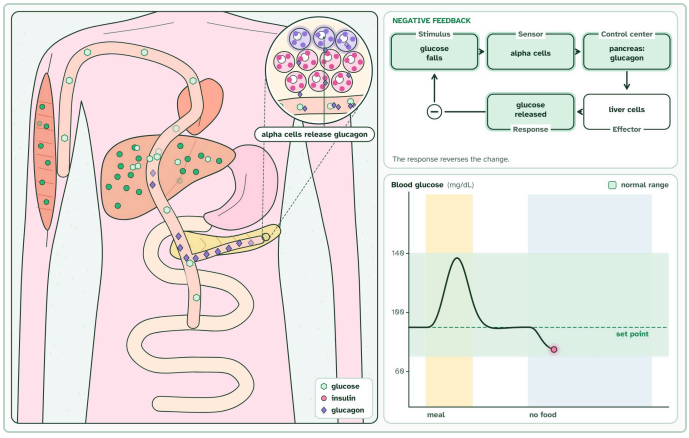
Insulin binds to receptors on **liver and muscle cells**, the effectors. They take glucose in and store it as **glycogen**.

4 GLUCOSE 90 MG/DL



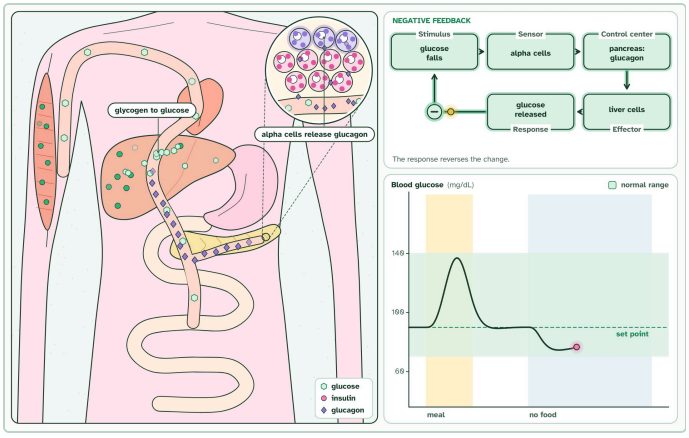
Blood glucose falls back to the set point, so less insulin is released. The response has removed the stimulus: **negative feedback**.

5 GLUCOSE 75 MG/DL



Alpha cells in the islets detect the fall and release the hormone **glucagon**.

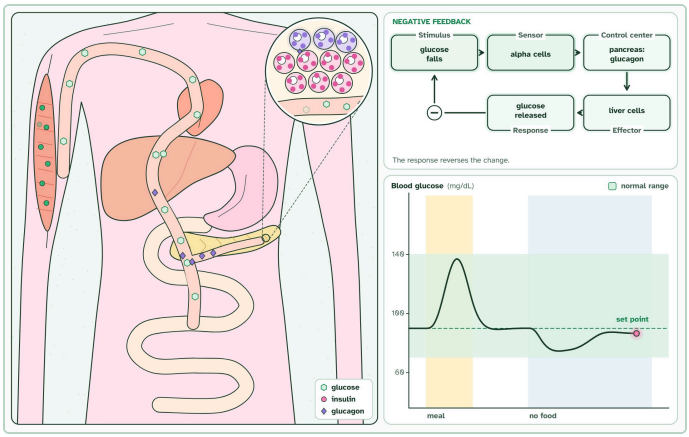
6 GLUCOSE 75 MG/DL



Glucagon acts on **liver cells**, which break glycogen down to glucose and release it into the blood. Muscle has no glucagon receptors.

7

GLUCOSE 85 MG/DL



The level rises back to the set point and less glucagon is released. Two hormones with opposite effects hold blood glucose steady.

Watch it move, and change it as it runs: biologybybradford.com/guides/ap-biology-unit-4-feedback#glucose

PREDICT

You skip breakfast and then play soccer for an hour. Which change happens in your blood and your liver?

(A) Glucagon rises, and liver cells break glycogen down and release glucose into the blood

(B) Insulin rises, and muscle cells release glucose from their glycogen into the bloodstream

(C) Glucagon rises, and muscle cells break down their glycogen and send the glucose to the brain

(D) Insulin falls to zero, and liver cells stop using any glucose until the next meal arrives

Decide before you look. Answer on page 30.

REMEMBER IT

Which hormone does which

I	G
In	Gone
Insulin	**Glucagon**
glucose goes into cells	glucose gone: the liver releases some

WATCH OUT

Glucagon is not glycogen. Glucagon is a hormone, a messenger in the blood; glycogen is the stored polysaccharide it tells the liver to break down. The names differ by a few letters; the molecules could hardly differ more.

04 4.4.A FEEDBACK
A *broken* loop

Diabetes mellitus is what happens when the glucose loop fails: the level stays high after meals and often between them. Where the loop breaks decides the type.

In **type 1 diabetes** the immune system destroys the beta cells. The stimulus is there and liver and muscle cells could respond, but no insulin is sent. In the film, No insulin is switched on: glucose climbs after the meal and stays high. Treatment replaces the missing signal, with insulin injected or pumped and matched to food and exercise.

In **type 2 diabetes** the beta cells still make insulin, but the target cells respond weakly: **insulin resistance**. It is a fault in signal transduction (4.3): insulin binds its receptor, but fewer of the steps inside the cell follow, so fewer glucose transporters reach the cell membrane. Risk rises with excess body fat, little exercise, age and family history; diet, exercise and drugs that make cells more sensitive come first in treatment.

Above about 180 mg/dL the kidneys cannot take back all the glucose they filter, so it spills into the urine and pulls water with it. Thirst and frequent urination are often the first signs.

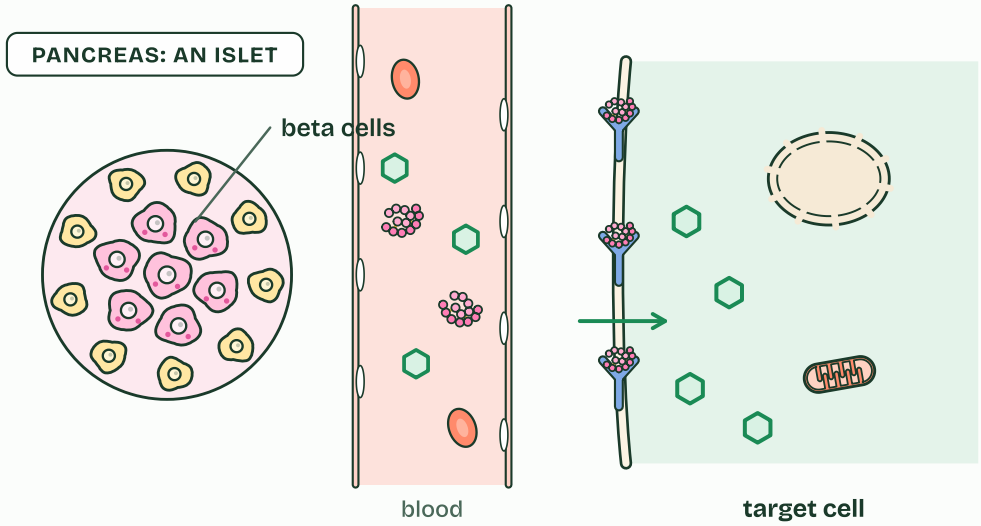
KEY POINTS

- Type 1: beta cells destroyed, so no insulin is released; treated with insulin.
- Type 2: insulin is released, but target cells respond poorly (insulin resistance).
- Either way the response fails, so glucose stays above its normal range.

KEY TERMS

diabetes mellitus
A condition in which blood glucose stays too high, because insulin is missing or target cells respond to it poorly.

insulin resistance
A state in which target cells respond less to insulin, so the same amount of insulin moves less glucose out of the blood.

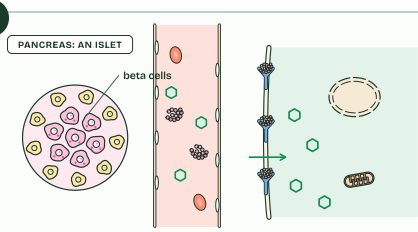


Healthy: beta cells make insulin, it binds receptors,
cells take up glucose, and blood glucose stays in range.

SWITCH IT

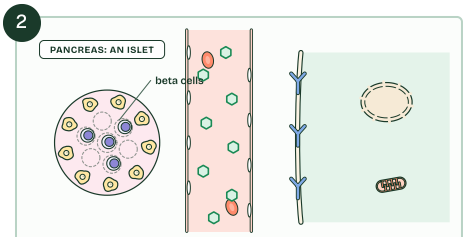
3 SETTINGS

1



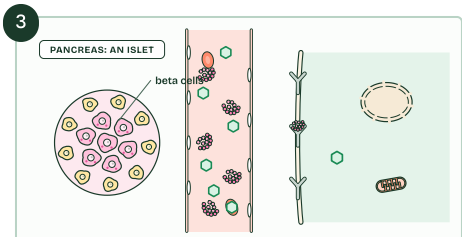
Healthy

2



Type 1

3

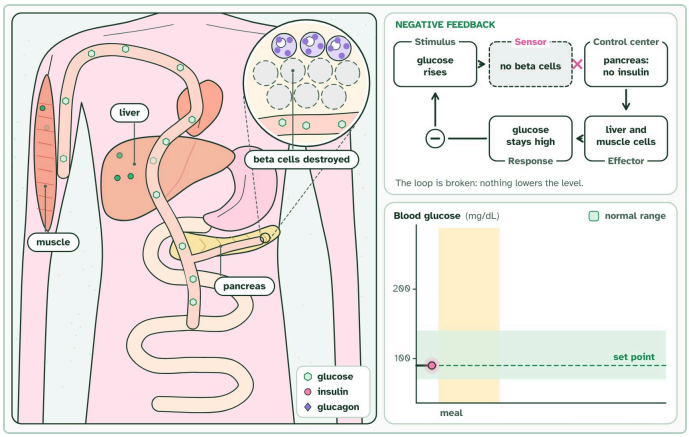


Type 2

ANIMATION · NO INSULIN: TYPE 1 DIABETES

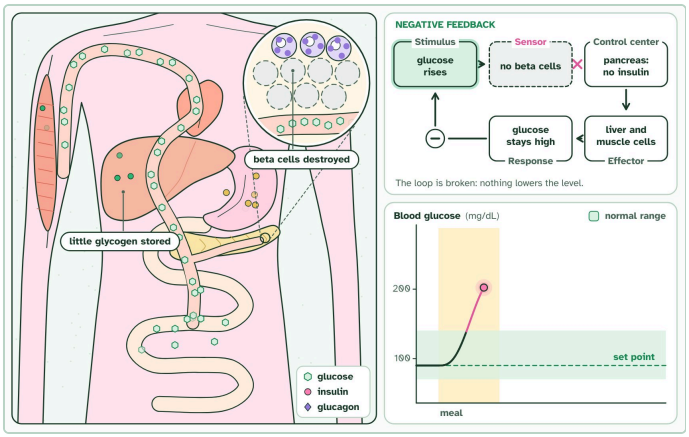
4 MOMENTS

1 GLUCOSE 90 MG/DL



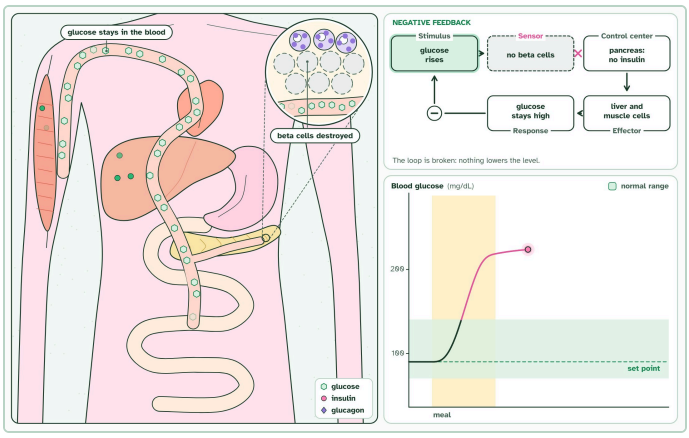
Type 1 diabetes. The immune system has destroyed the beta cells, so the pancreas makes little or no insulin.

2 GLUCOSE 200 MG/DL



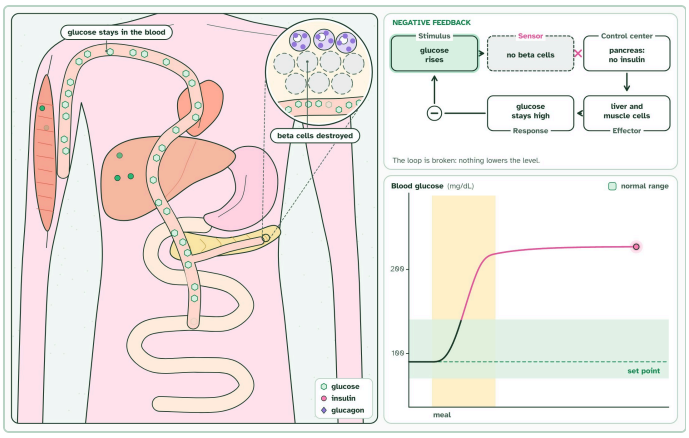
A meal raises blood glucose as before. The stimulus is there, but no insulin is released.

3 GLUCOSE 225 MG/DL



Without insulin, liver and muscle cells take in very little glucose, so they store almost no glycogen. The loop is broken and nothing brings the level down.

4 GLUCOSE 225 MG/DL



Blood glucose stays far above the normal range (hyperglycemia) and some is lost in the urine. The treatment is insulin, injected or pumped, matched to each meal.

Watch it move, and change it as it runs: biologybybradford.com/guides/ap-biology-unit-4-feedback#diabetes

PREDICT

Early in type 2 diabetes, blood tests often show more insulin than in a healthy person. Why would the pancreas release extra insulin?

(A) The beta cells have been damaged by the disease, and damaged cells leak out every hormone they hold

(B) The liver has run out of glycogen, so the pancreas sends extra insulin to help it build new stores

(C) Glucose stays above the set point, so the stimulus persists and the beta cells keep on signaling

Decide before you look. Answer on page 30.

WATCH OUT

Type 1 diabetes is not caused by eating sugar: it is an immune attack on the beta cells. Type 2 is linked to body fat and exercise, but genes and age matter too.

05 Too hot, *too cold*

4.4.A FEEDBACK

Your core temperature stays near 98.6 °F whether you sit in a sauna or walk through snow. Thermoreceptors in the skin and in the brain are the sensors. The control center is the **hypothalamus**, at the base of the brain, which signals the effectors along nerves.

When you heat up, sweat glands release sweat, which carries heat away as it evaporates from the skin. The arterioles that supply the skin widen (**vasodilation**), so more warm blood flows near the surface and loses heat to the air: that is why a hot face looks flushed.

When you cool down, the skin's arterioles narrow (**vasoconstriction**), keeping warm blood deeper in the body. Skeletal muscles **shiver**, and their respiration releases heat. Tiny muscles pull the hairs upright: in a furry mammal that traps a layer of air, and in you it makes goose bumps.

Two sets of effectors, one for each direction, each reversing the change that set it off. It is negative feedback again, with nerve signals in place of hormones.

KEY POINTS

- Too hot: sweating and vasodilation lose more heat.
- Too cold: vasoconstriction keeps heat in; shivering releases more.
- The hypothalamus is the control center; nerves carry its signals.

KEY TERMS

hypothalamus
A small region at the base of the brain that is the control center for body temperature, and that controls the pituitary gland.

vasodilation
The widening of arterioles, which lets more blood flow through the tissue they supply.

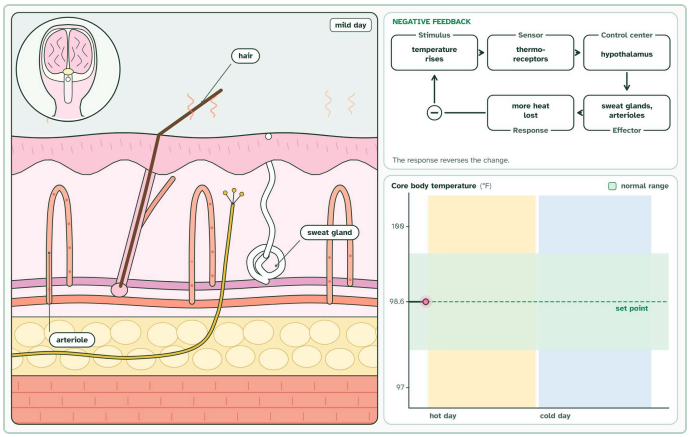
vasoconstriction
The narrowing of arterioles, which lets less blood flow through the tissue they supply.

shiver
Rapid, small, involuntary contractions of skeletal muscle, whose respiration releases heat.

ANIMATION · BODY TEMPERATURE HELD STEADY

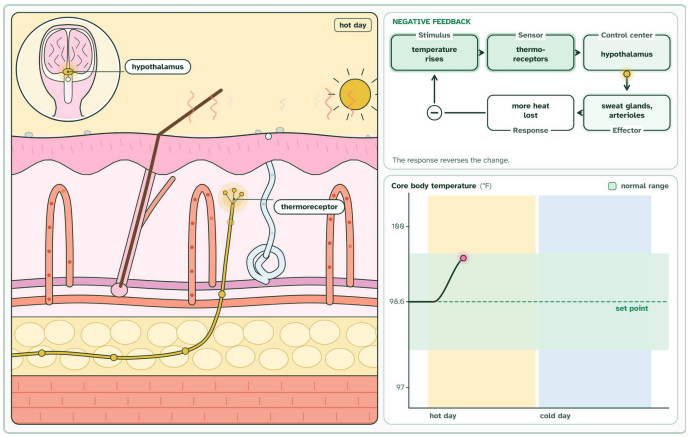
7 MOMENTS

1 CORE 98.6 °F



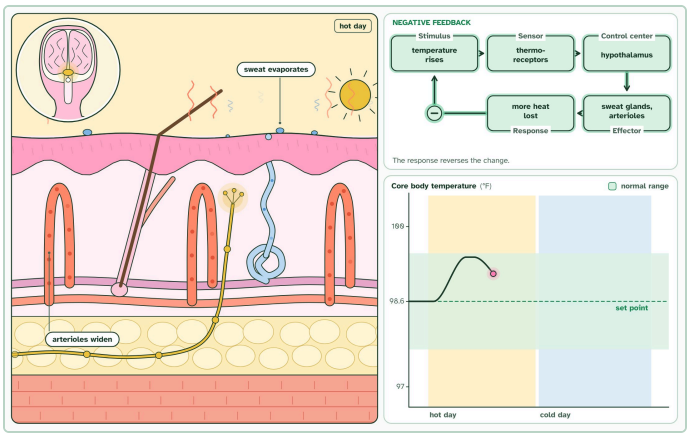
Core body temperature is held close to a **set point** of about 37 °C (98.6 °F), whatever the weather.

2 CORE 99.4 °F



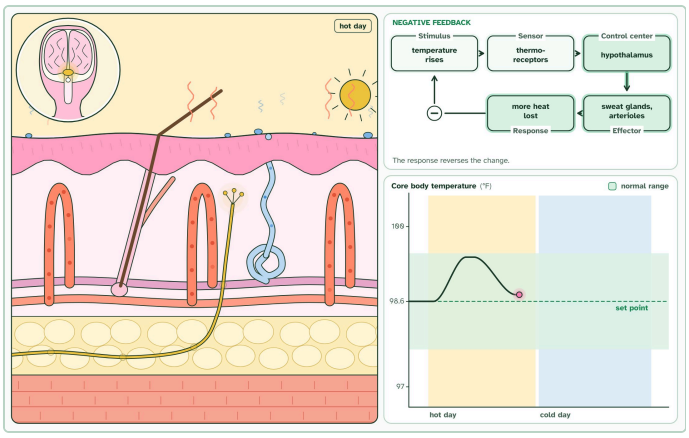
Thermoreceptors in the skin and in the brain detect the change. The **hypothalamus**, the control center, compares it with the set point.

3 CORE 99.1 °F



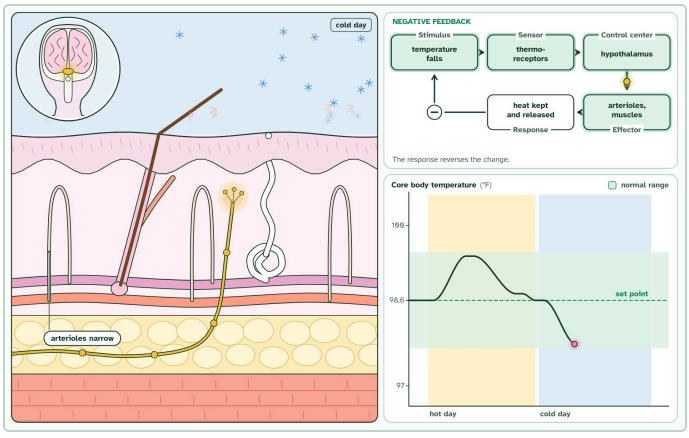
It signals the effectors. **Sweat glands** release sweat, which takes heat away as it evaporates, and the skin's arterioles widen (**vasodilation**), so more warm blood flows near the surface.

4 CORE 98.7 °F



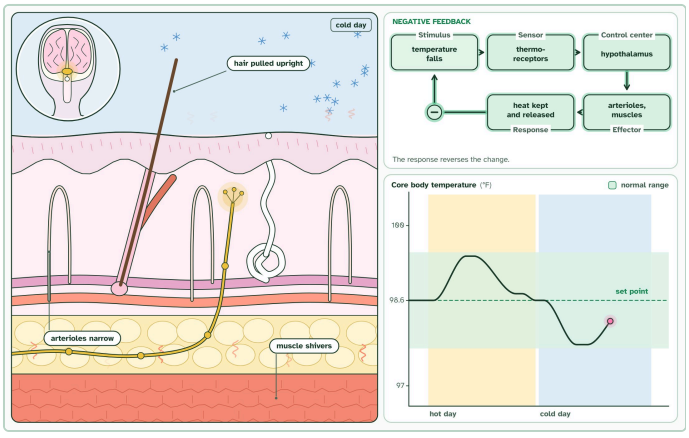
More heat is lost, and the temperature falls back to the set point: **negative feedback**.

5 CORE 97.8 °F



The hypothalamus signals other effectors. The skin's arterioles narrow (**vasoconstriction**), so less blood flows near the surface and less heat is lost.

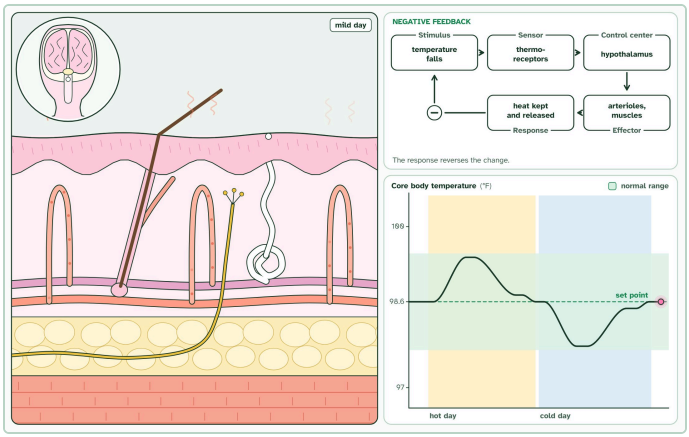
6 CORE 98.2 °F



Skeletal muscles **shiver**, and their respiration releases heat. Hairs are pulled upright.

7

CORE 98.6 °F



The temperature rises back to the set point. Hot or cold, the response reverses the change that caused it.

Watch it move, and change it as it runs: biologybybradford.com/guides/ap-biology-unit-4-feedback#temperature

PREDICT

On a hot, humid day, sweat drips off you instead of drying. Why do you feel hotter than on an equally hot, dry day?

(A) Sweat cools you only as it evaporates, and humid air slows evaporation, so less heat leaves you

(B) Humid air holds more heat than dry air, so the water in it warms the skin faster than sweat cools it

(C) The sweat glands shut down in humid air, so the body has to rely on vasodilation alone to lose heat

Decide before you look. Answer on page 30.

WATCH OUT

The blood vessels do not move nearer to the skin or farther from it. The arterioles that feed the skin's capillaries widen or narrow, which changes how much blood flows near the surface.

06

4.4.A FEEDBACK

A loop that *runs away*

Not every loop pulls a variable back. In **positive feedback** the response adds to the stimulus, so the change grows, and grows faster. That would wreck homeostasis, so the body saves it for events that must be finished quickly and completely.

Childbirth is the classic case. As labor begins, the baby's head presses on the cervix, the neck of the uterus. Stretch receptors there send nerve impulses to the hypothalamus, which makes the posterior pituitary release the hormone **oxytocin** into the blood. Oxytocin makes the muscle of the uterus wall contract harder. A harder contraction pushes the head harder on the cervix: more stretch, more oxytocin, stronger contractions.

Nothing inside the loop can stop it, because each turn feeds the next. It ends with an event outside the loop, the birth itself, which takes the pressure off the cervix. The stimulus has gone, and the contractions die away.

KEY POINTS

- Positive feedback: the response amplifies the stimulus.
- Labor: stretch of the cervix, the hypothalamus, oxytocin from the posterior pituitary, stronger contractions.
- An event outside the loop, the birth, stops it.

KEY TERMS

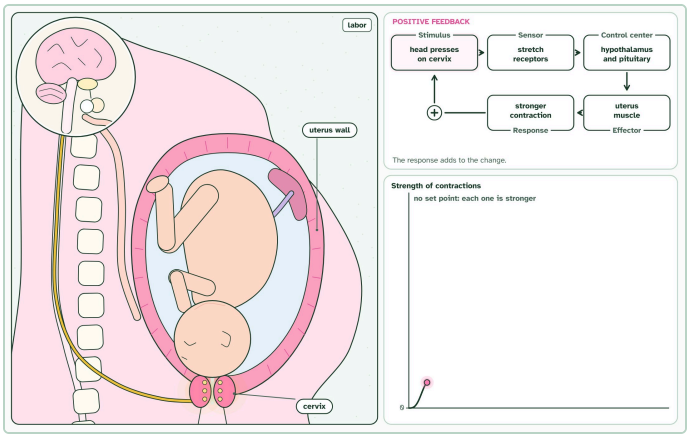
positive feedback
Control in which the response adds to the stimulus, amplifying it and moving the variable farther from where it started.

oxytocin
A hormone released by the posterior pituitary that makes the muscle of the uterus contract in labor and squeezes milk out of the mammary glands.

ANIMATION · A LOOP THAT RUNS AWAY: BIRTH

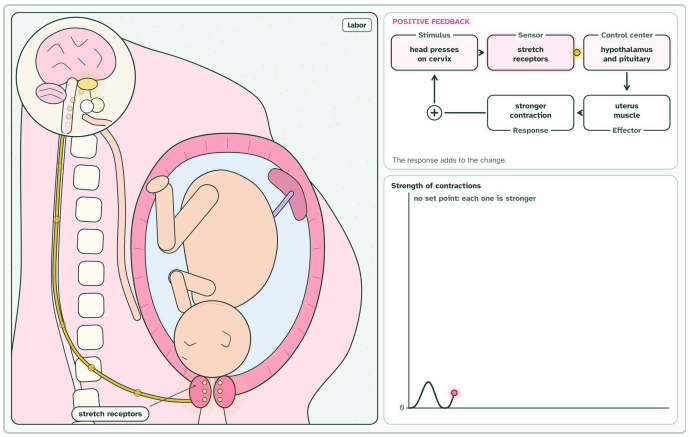
7 MOMENTS

1 WEAK CONTRACTIONS



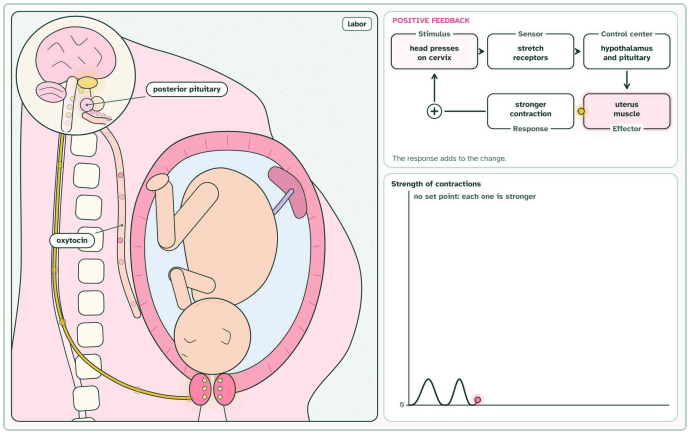
Late in pregnancy the baby lies head down. As labor begins, weak contractions of the uterus press the baby's head against the **cervix**.

2 THE FIRST TURN



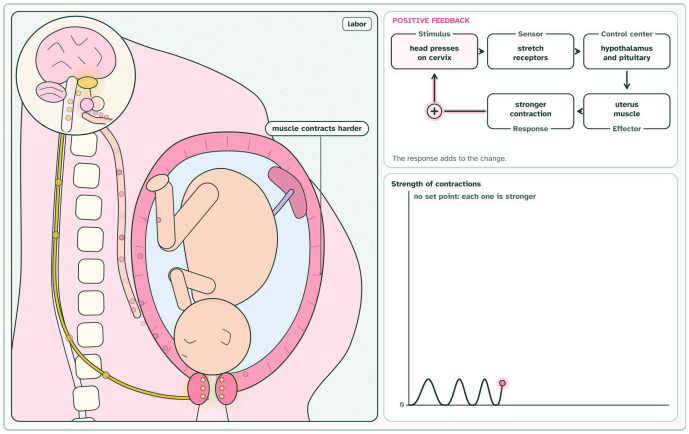
The pressure stretches the cervix. **Stretch receptors** there fire, and nerve impulses carry the message to the brain.

3 THE FIRST TURN



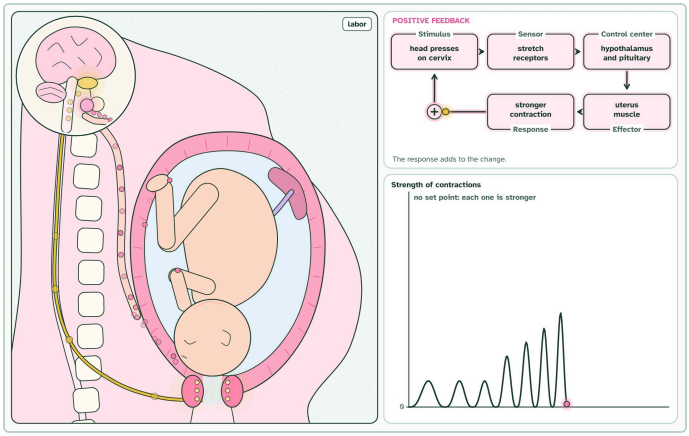
The hypothalamus makes the **posterior pituitary** release the hormone **oxytocin** into the blood.

4 THE FIRST TURN



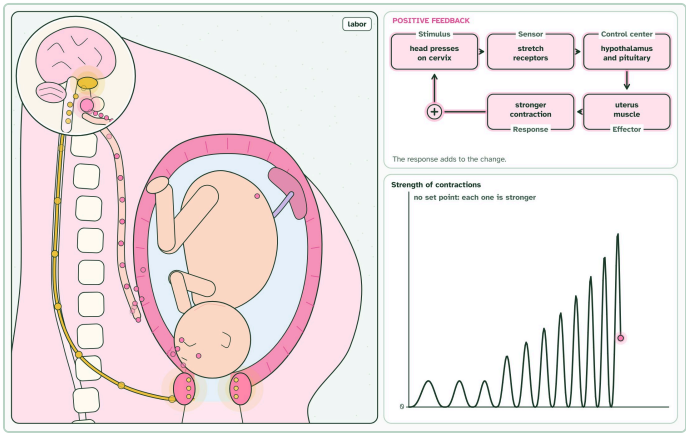
Oxytocin reaches the muscle of the uterus wall, the effector, and it **contracts harder**.

5 OXYTOCIN RISING



Round and round, each turn stronger and sooner than the last. This is **positive feedback**: the change is pushed further, not back to a set point.

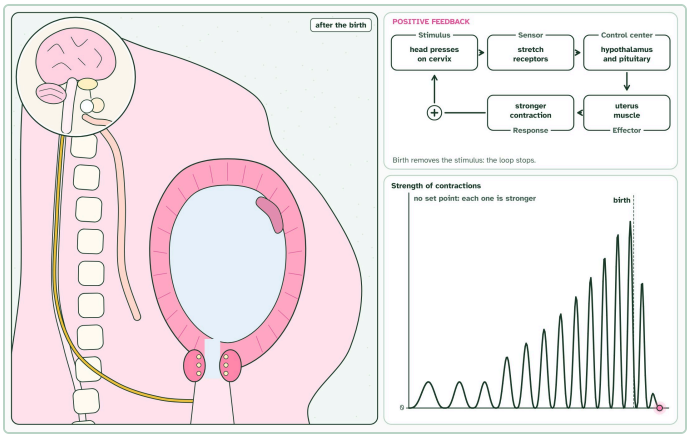
6 OXYTOCIN RISING



The loop runs away until the baby is born. Birth takes the pressure off the cervix: the stimulus has gone, so the loop stops.

7

THE LOOP HAS STOPPED



Negative feedback holds a value steady. Positive feedback drives a process quickly to its end, and it takes an outside event, here the birth, to stop it.

Watch it move, and change it as it runs: biologybybradford.com/guides/ap-biology-unit-4-feedback#labor

PREDICT

A doctor gives a slow drip of synthetic oxytocin to a woman whose labor has stalled. Why can a small dose get contractions going strongly?

(A) Oxytocin works on the baby, not the uterus, and tells the baby to start pushing its own way out

(B) Stronger contractions press the head on the cervix, which releases more of the body's own oxytocin

(C) The drip stands in for the cervix's stretch receptors, so the loop no longer needs a signal at all

Decide before you look. Answer on page 30.

EXAMPLE

Not on the AP list, but the same shape: at a cut, platelets that stick to the wound release chemicals that call in more platelets, until a plug seals the hole.

WATCH OUT

Positive feedback is not good feedback. It pushes the variable farther from where it started, and it keeps going until an outside event stops it.

07

4.4.A FEEDBACK

Ripe fruit and *full milk*

Plants use positive feedback too. A ripening fruit releases **ethylene**, a small gas that acts as a plant hormone. Ethylene switches on the changes of ripening: chlorophyll is broken down, starch turns to sugar, the cell walls soften. It also switches on the fruit's own ethylene production. So a ripening fruit makes more ethylene, which ripens it faster, which makes more ethylene still.

Because ethylene is a gas, it reaches the neighbors. One ripe banana in a closed box of green ones sets them all off within days, which is why one ripe fruit in a bag speeds the others. Make the prediction below, then test it with the film's controls.

Lactation is the other AP example. When a baby suckles, touch receptors in the nipple send impulses to the hypothalamus. The anterior pituitary releases **prolactin**, which drives milk production, and the posterior pituitary releases oxytocin, which squeezes milk out of the glands. The milk flows, the baby keeps suckling, and more oxytocin follows: a positive loop. It stops when the baby stops feeding, again an event outside the loop.

KEY POINTS

- Ripening: ethylene makes the fruit ripen and make more ethylene.
- Lactation: suckling, then prolactin (milk made) and oxytocin (milk let out).
- Both stop when something outside the loop changes.

KEY TERMS

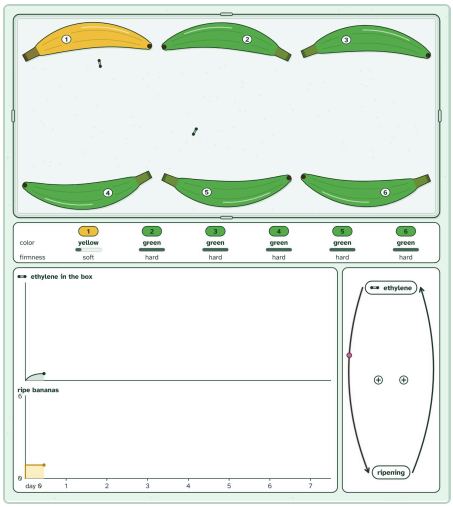
ethylene
A plant hormone, a small gas, that sets off fruit ripening and its own further production.

prolactin
A hormone from the anterior pituitary that makes the mammary glands produce milk.

ANIMATION · ONE RIPE BANANA

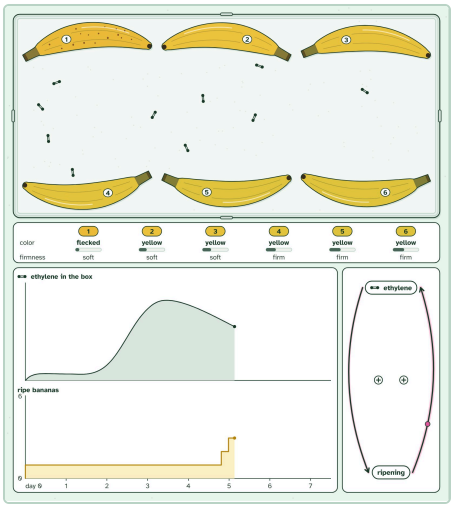
4 MOMENTS

1 DAY 0 · 1 OF 6 RIPE



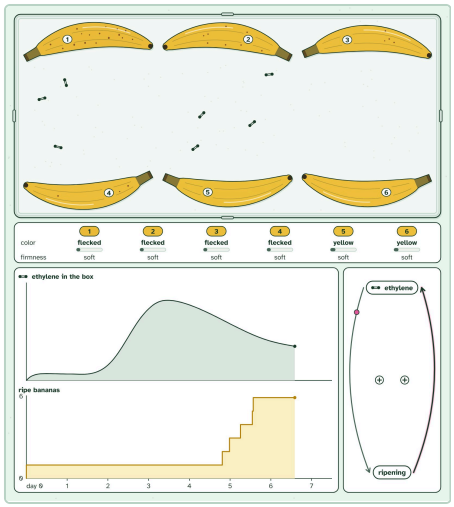
The ripe banana gives off **ethylene**, a gas that spreads through the air in the box.

2 DAY 5 · 3 OF 6 RIPE



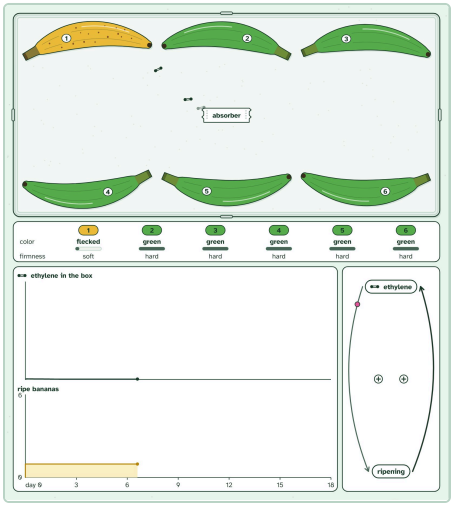
One ripening banana sets off the next, so the whole box ripens **fast and together**.

3 DAY 6 · 6 OF 6 RIPE



All six are ripe. The loop runs out: ripe fruit give off less ethylene, and the gas falls.

4 DAY 6 · 1 OF 6 RIPE



The same day with an ethylene absorber in the box: the five green bananas have not yet started to ripen.

Watch it move, and change it as it runs: biologybybradford.com/guides/ap-biology-unit-4-feedback#ripening

PREDICT

A fruit seller puts one ripe banana in a closed box with five green ones, and adds a sachet that absorbs ethylene. Compared with a box without the sachet, what happens?

(A) They ripen at the same time, because ripening depends only on each banana's own age, not on any gas

(B) They ripen sooner, because the sachet traps the ethylene and holds it right beside the green bananas

(C) The ripe banana turns green again, because the sachet takes back the ethylene that ripened it to start

(D) They ripen days later, because the gas is taken up before it can set off the loop in the green ones

Decide before you look. Answer on page 30.

REMEMBER IT

The AP examples of positive feedback

B Babies	L Like	R Ripe
Birth oxytocin and contractions	**Lactation** suckling and milk let-down	**Ripening** ethylene makes ethylene

08

4.4.A FEEDBACK

Back to the set point, or *on to the end*

Side by side, the two kinds of feedback differ in direction. Negative feedback opposes a change, so the variable returns to its set point and hovers there. Positive feedback amplifies a change, moving the variable ever farther from where it started, until something outside the loop ends it.

So they do different jobs. Negative feedback holds anything that must stay steady for life: glucose, temperature, water. Positive feedback drives one-off processes that must run to completion fast: a birth, the let-down of milk, a fruit ripening, a blood clot.

Feedback also works inside a single cell, molecule by molecule. In **feedback inhibition**, the end product of a pathway binds the pathway's first enzyme at an allosteric site and slows it (Unit 3, enzymes): the more product there is, the less is made. Gene expression can work the same way. In the *lac* operon of *E. coli* (6.5), lactose switches on the genes for the enzymes that break it down; once the lactose is used up, the repressor binds again and the genes switch off.

Two kinds of feedback

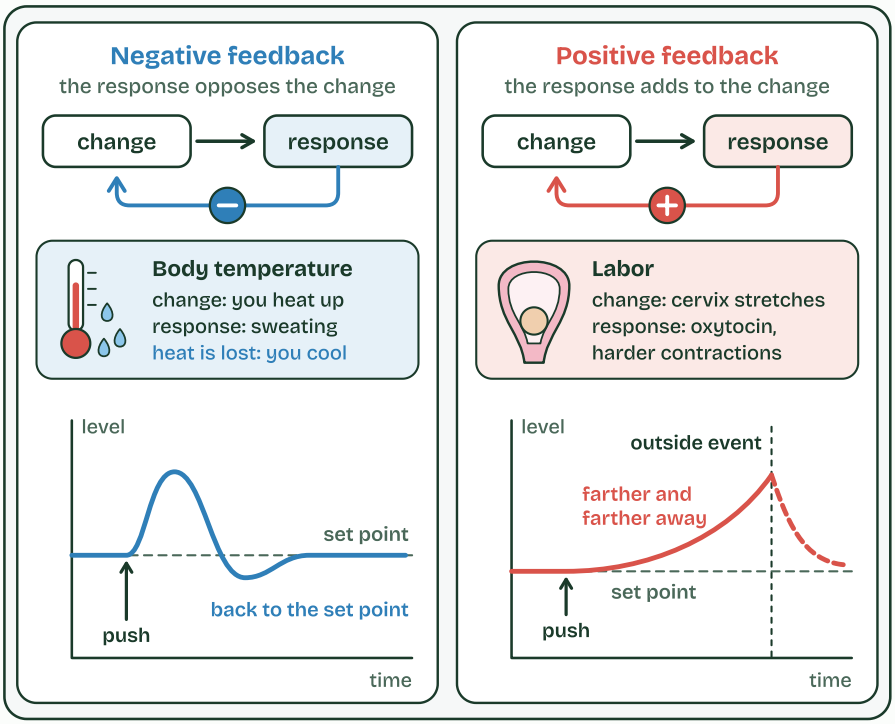
	Negative	Positive
The response	opposes the change	adds to the change
The variable	returns to its set point	moves farther from it
What stops it	the loop itself, once the change is undone	an event outside the loop
Used for	keeping conditions steady	finishing a process fast
AP examples	blood glucose, body temperature, feedback inhibition, the *lac* operon	labor, lactation, fruit ripening

KEY POINTS

- Negative: back to the set point. Positive: away to an end point.
- Negative feedback works in whole bodies and inside single cells.
- Feedback inhibition: the end product slows its own pathway.

KEY TERMS

feedback inhibition
Control in which the end product of a metabolic pathway inhibits an enzyme early in the pathway, so the product slows its own production.



The same push on two kinds of loop. Follow each trace from its set point.

PREDICT

A pathway is controlled by feedback inhibition. The cell suddenly starts using up the pathway's end product. What happens to the pathway's first enzyme?

(A) It becomes more active, because less product is left to bind it, so the pathway speeds up to match

(B) It becomes less active, because the cell has already spent the product it needed on its own work

(C) It is broken down, because the product that kept it folded is no longer there to protect it

Decide before you look. Answer on page 31.

Key terms

Every term this guide defines, A to Z, with the chapter it is in. Cover the right-hand side and test yourself.

alpha cells 03
Cells in the pancreatic islets that release glucagon when blood glucose falls.

beta cells 03
Cells in the pancreatic islets that release insulin when blood glucose rises.

control center 02
The part of a loop, such as the hypothalamus or the islets of the pancreas, that compares the variable with its set point and sends a signal to the effectors.

diabetes mellitus 04
A condition in which blood glucose stays too high, because insulin is missing or target cells respond to it poorly.

effector 02
A muscle or gland that receives the control center's signal and acts on it.

ethylene 07
A plant hormone, a small gas, that sets off fruit ripening and its own further production.

feedback inhibition 08
Control in which the end product of a metabolic pathway inhibits an enzyme early in the pathway, so the product slows its own production.

glucagon 03
A hormone from the alpha cells of the pancreas that raises blood glucose: liver cells break glycogen down and release glucose into the blood.

glycogen 03
A branched polysaccharide of glucose, stored in liver and muscle cells.

homeostasis 01
The maintenance of a stable internal environment, with each controlled variable held within a narrow range, despite changes inside and outside the body.

hypothalamus 05
A small region at the base of the brain that is the control center for body temperature, and that controls the pituitary gland.

insulin 03
A hormone from the beta cells of the pancreas that lowers blood glucose: liver, muscle and fat cells take glucose in, and liver and muscle store it as glycogen.

insulin resistance 04
A state in which target cells respond less to insulin, so the same amount of insulin moves less glucose out of the blood.

negative feedback 02
Control in which the response opposes the stimulus, so a perturbed variable is returned to its set point.

normal range 01
The band of values around a set point within which a variable is allowed to wander without a correction.

oxytocin 06
A hormone released by the posterior pituitary that makes the muscle of the uterus contract in labor and squeezes milk out of the mammary glands.

positive feedback 06
Control in which the response adds to the stimulus, amplifying it and moving the variable farther from where it started.

prolactin 07
A hormone from the anterior pituitary that makes the mammary glands produce milk.

response 02

What the effector does, which changes the variable.

sensor 02

A cell or organ that detects the stimulus; often called a receptor.

set point 01

The value of a controlled variable that a feedback system works to return it to.

shiver 05

Rapid, small, involuntary contractions of skeletal muscle, whose respiration releases heat.

stimulus 02

A change in a controlled variable, away from its set point, that a feedback loop detects.

vasoconstriction 05

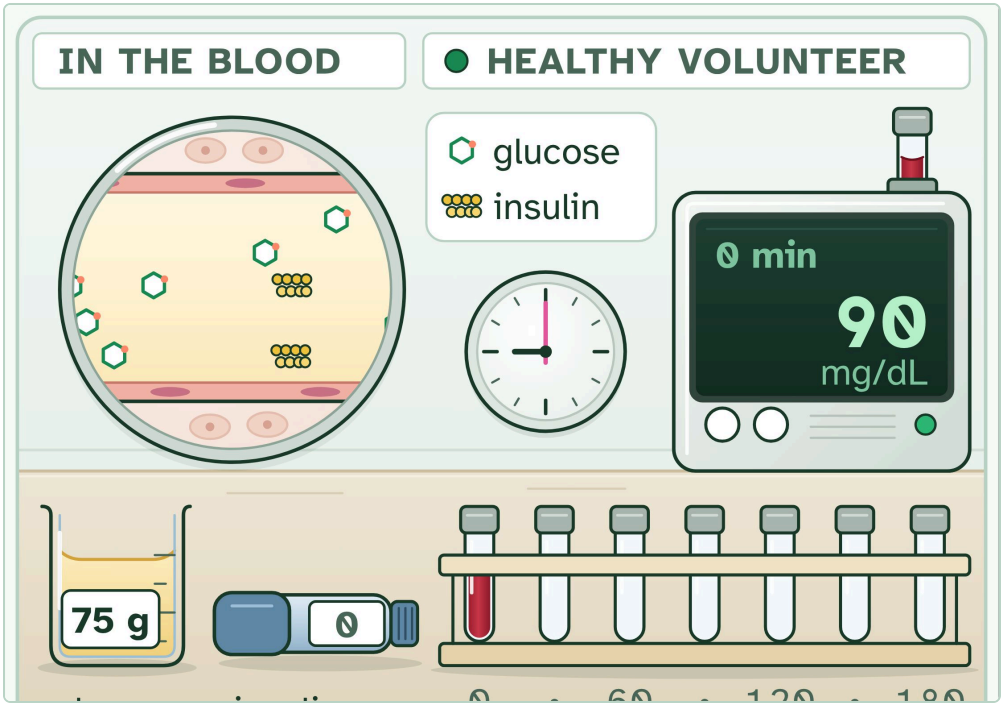
The narrowing of arterioles, which lets less blood flow through the tissue they supply.

vasodilation 05

The widening of arterioles, which lets more blood flow through the tissue they supply.

Dry lab: *Glucose tolerance*

A volunteer drinks glucose and a sample of blood is taken every half hour. Test a healthy person and someone with each type of diabetes, and see which part of the control loop has failed.



Run it online: change the variables, run the trials, and the table and graph fill in as you go.
`biologybybradford.com/guides/ap-biology-unit-4-feedback#lab`

Your question

How does blood glucose change after a glucose drink in a healthy person, and how are the curves different in type 1 and type 2 diabetes?

What you can change

The person, the drink (glucose, or water as the control) and, for type 1 diabetes, a dose of insulin before the drink. Everything else stays the same: a ten-hour fast first, 75 g of glucose, and a blood sample every 30 minutes for three hours.

What to record

For each test, the fasting level, the peak, the time of the peak and the level at two hours. Glucose is in mg/dL, as on US glucose meters. Repeat a test to see the measurement wobble, and download the CSV to plot your own.

Find out

- **What does a healthy person do?** Run the glucose drink, then the water control. How high does the level rise, when does it peak, and how long does it take to come back?
- **How is type 1 diabetes different?** Run it with no insulin. Compare the fasting level, the peak and the level at two hours with the healthy person's.
- **Can injected insulin stand in for the beta cells?** Run type 1 with 4, 8 and then 12 units before the drink. Which dose comes closest to a healthy curve, and what could go wrong with too much?
- **And type 2?** Run it. The curve looks a little like type 1, but the broken link is a different one. What would you measure in the blood to tell them apart?

Record

- For each test: the person, the drink, the insulin dose, and the readings in the table.
- The fasting level, the peak and its time, and the level at two hours, against the dashed thresholds of 126 and 200 mg/dL.
- A repeat of one test, to see how much of a difference between two curves could be measurement error.
- Download the CSV to plot your own graph.

Your question How does blood glucose change after a glucose drink in a healthy person, and how are the curves different in type 1 and type 2 diabetes?**What you can change**The person, the drink (glucose, or water as the control) and, for type 1 diabetes, a dose of insulin before the drink. Everything else stays the same: a ten-hour fast first, 75 g of glucose, and a blood sample every 30 minutes for three hours.**What to record**For each test, the fasting level, the peak, the time of the peak and the level at two hours. Glucose is in mg/dL, as on US glucose meters. Repeat a test to see the measurement wobble, and download the CSV to plot your own.

Back to the feedback loop

Use your curves to explain how negative feedback brings blood glucose back to its set point after the drink, and which part of the loop is disrupted in type 1 and in type 2 diabetes.

QUESTIONS ON THE LAB

QUESTION 1

You give the healthy volunteer plain water instead of the glucose drink. What does the blood glucose do over the three hours?

(A) It rises a little and then falls, because the body answers any drink by releasing insulin

(B) It falls steadily all the way, because the water dilutes the glucose already in the blood

(C) It stays close to the fasting level, because nothing has been added to the blood to change it

Answer on page 31.

QUESTION 2

Type 1 diabetes with no insulin, then with 10 units injected first. Which part of the curve changes most?

(A) The peak and the level at two hours, because the insulin acts over the next hour or two

(B) The fasting level at time 0, because the injection goes in just before the drink is taken

(C) Nothing at all, because the person's beta cells are still missing and cannot respond

Answer on page 31.

Check yourself

The check for this guide is online: a fresh paper of past-paper style questions from the exam bank on 4.4 each time, marked as you go, and saved to your Exam practice progress when you are signed in. Scan the code, or type the link.

biologybybradford.com/exam-maker/sit?program=ap&units=U4&ced=4.4&paper=quiz&marks=15&src=ep

Answers

PREDICTIONS IN THE CHAPTERS

01 On a winter walk the air drops from 68 °F to 40 °F (20 °C to 4 °C). What happens to the core temperature of a healthy walker?

B **It stays within about a degree of 98.6 °F, because the body changes how much heat it makes and loses**

Core temperature barely moves. The body loses heat faster in the cold, but it answers by keeping warm blood away from the skin and by shivering, so the inside changes by a tiny fraction of the change outside. That answer is chapter 5.

02 A drug stops the sensors in a negative feedback loop from detecting anything. The variable then drifts above its set point. What happens next?

C **Nothing corrects it, because no signal reaches the control center, so the effector never acts**

The sensor is the first link. With it gone the control center gets no news of the rise, sends no signal, and the effector does nothing. The loop is broken, so the variable wanders wherever the outside pushes it. Chapter 4 is a real case.

03 You skip breakfast and then play soccer for an hour. Which change happens in your blood and your liver?

A **Glucagon rises, and liver cells break glycogen down and release glucose into the blood**

The fast and the exercise both lower blood glucose, so alpha cells release glucagon and the liver turns glycogen back into glucose for the blood. Working muscle does break down its own glycogen, but it keeps that glucose for itself: it cannot release it into the blood, and it has no glucagon receptors.

04 Early in type 2 diabetes, blood tests often show more insulin than in a healthy person. Why would the pancreas release extra insulin?

C **Glucose stays above the set point, so the stimulus persists and the beta cells keep on signaling**

The loop is still running; only its last link is weak. Because the cells take up glucose poorly, the level stays high, the stimulus never goes away, and the beta cells keep releasing insulin. Over years they can wear out, and then insulin falls too.

05 On a hot, humid day, sweat drips off you instead of drying. Why do you feel hotter than on an equally hot, dry day?

A **Sweat cools you only as it evaporates, and humid air slows evaporation, so less heat leaves you**

Turning liquid sweat into vapor takes heat from the skin. In humid air less sweat evaporates, so it drips off carrying little heat away. The hypothalamus keeps the glands working hard, which is why you end up soaked and still hot.

06 A doctor gives a slow drip of synthetic oxytocin to a woman whose labor has stalled. Why can a small dose get contractions going strongly?

B **Stronger contractions press the head on the cervix, which releases more of the body's own oxytocin**

The drip only has to start the loop. Its oxytocin strengthens the contractions, the head presses harder on the cervix, and the body's own oxytocin follows, turn after turn. Doctors still watch closely, because a loop that amplifies itself can make contractions too strong.

07 A fruit seller puts one ripe banana in a closed box with five green ones, and adds a sachet that absorbs ethylene. Compared with a box without the sachet, what happens?

D **They ripen days later, because the gas is taken up before it can set off the loop in the green ones**

The sachet keeps the gas low, so the green bananas never get the push that starts their own ethylene burst. In the film they ripen on their own slow clocks, more than a week later and days apart; without the sachet all five are ripe within about six days.

08 A pathway is controlled by feedback inhibition. The cell suddenly starts using up the pathway's end product. What happens to the pathway's first enzyme?

A **It becomes more active, because less product is left to bind it, so the pathway speeds up to match**

With the product being used up, fewer product molecules sit on the enzyme's allosteric site, so more enzyme is active and the pathway runs faster until supply matches demand. The response opposes the change in the product's level: negative feedback, in one cell.

QUESTIONS ON THE DRY LAB

Q1 You give the healthy volunteer plain water instead of the glucose drink. What does the blood glucose do over the three hours?

C **It stays close to the fasting level, because nothing has been added to the blood to change it**

It stays near the fasting level, about 90 mg/dL. The water control shows that the rise in the other tests is caused by the glucose, and that taking the samples does not change the result.

Q2 Type 1 diabetes with no insulin, then with 10 units injected first. Which part of the curve changes most?

A **The peak and the level at two hours, because the insulin acts over the next hour or two**

Injected insulin does the missing link's job: liver and muscle take glucose in, so the peak is lower and the level falls back faster. The beta cells are still gone, which is why the dose has to be repeated and matched to food and exercise.

How this was made. The course structure, the activities and the teaching choices come from my own classroom, my presentations and my years of teaching IB and AP Biology. I use Claude, an AI, to help write and build the interactive guides, lesson plans, slides and practice questions, and to draw the diagrams and code the interactives. I direct the work and review it against the IB and AP specifications before it goes live.

Written and drawn for Biology by Bradford, biologybybradford.com. Free to print and share with a class.