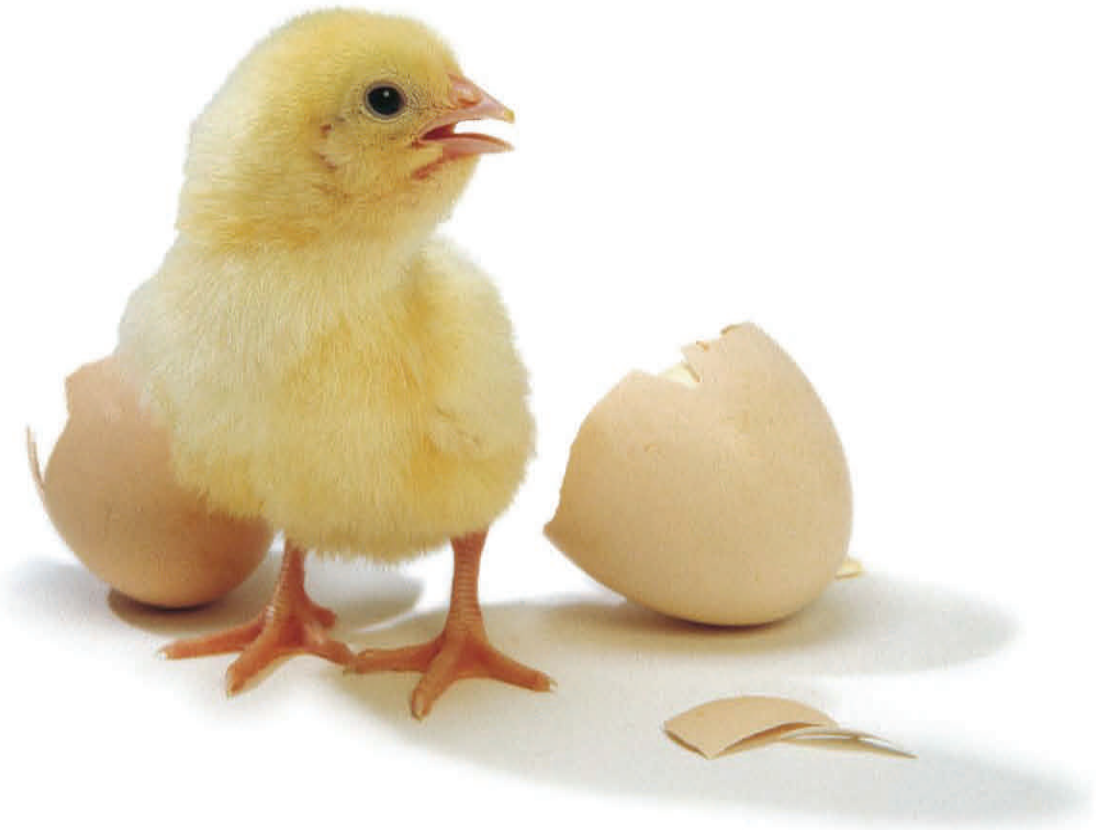
Incubation and Embryology

The Egg Story



Lesson Plan

Brinsea

Mini Advance Classroom Pack

Table of contents

Introduction

An avian egg is amazing and exciting. What is more fascinating than to see a fully-developed baby chick emerge from an egg? Just three weeks of incubation transforms a seemingly lifeless chicken egg into an active, living being. A study of this transformation and of the different stages of embryonic development will uncover many interesting facts.

This manual has been designed to help you and your students study incubation and embryonic development. A hands-on experience of incubation of eggs with the Brinsea Mini Advance Classroom Pack will show the effects of heat, air, and moisture control on hatchability. But your students will also find out how an egg is formed, what its different parts and their functions are, and how a chick embryo develops and hatches. This will also give an interesting insight into particular biological topics such as blood circulation and respiration and how bones are different in birds.

This manual is divided into four sections. For each section, teaching materials are printed on yellow paper to distinguish them from reading materials and activities. Teaching materials include suggested student activities and vocabulary which is going to be encountered in the section. A glossary at the end of this manual is there to assist you introducing these scientific terms. According to grades, reading materials may be studied without your assistance as a basis for further discussion or you may choose to read it with the students and discuss as you go.

This curriculum has been correlated to the US National Science Education Standards (see page 3) and will also help reinforce Mathematics, Language Arts, Physical Development and Health skills. During this course, students will develop observation, data collection, analysis and record keeping skills as well as make and use measurements, ratios and percentages. They will be required to read, comprehend, interpret and evaluate written materials, listen critically and analytically and use written and spoken language for a variety of purposes. They will acquire a working knowledge of concepts and basic biological vocabulary as well as an understanding of nutrition, physical development, structure and function of the body. Further useful references have also been included at the end of this manual to consolidate the embryology project but also enhance programs in nutrition, mathematics and social sciences for instance.

Before you get involved with the project, we recommend you read the Brinsea Mini Advance classroom pack instruction manuals provided to familiarize yourself with the equipment, the principles of incubation and difficulties you may be facing.
An incubation checklist is provided to assist you. You may wish to set up the incubator and fill out the checklist with the students as an exercise on how to follow directions.

Correlation to US National Science Education Standards

This embryology project will help you meet the following national science standards:

Grades 3-5

Abilities necessary to conduct scientific inquiry
- Ask questions about objects, organisms and events in the environment.
- Plan and conduct a simple investigation.
- Use simple equipment and tools to gather data.
- Use data to construct a reasonable explanation.
- Communicate investigations and explanations.

The characteristics of organisms
- Organisms have basic needs and can survive only in environments in which their needs can be met.
- Each animal has different structures that serve different functions in growth, survival and reproduction.
- The behavior of individual organisms is influenced by internal and external cues.

Life cycles of organisms
- Animals have life cycles including birth, maturation, reproduction and death.
- Animals closely resemble their parents.

Organisms and their environments
- All animals depend on plants. Some animals eat plants for food while others eat animals that eat the plants.
- An organism's patterns of behavior are related to the nature of that organism's environment, including the kinds and numbers of organisms present, the availability of food, resources and physical characteristics of the environment.

Abilities of technological design
- Identify a simple problem.
- Propose a solution.
- Implement proposed solutions.
- Evaluate a product or design.
- Communicate a problem, design and solution.

Grades 6-8

Abilities necessary to conduct scientific inquiry
- Identify questions that can be answered through scientific investigations.
- Design and conduct a scientific investigation.
- Use appropriate tools and techniques to gather, analyze and interpret data.
- Develop descriptions, explanations, predictions and models using evidence.
- Think critically and logically to make the relationships between evidence and explanations.
- Recognize and analyze alternative explanations and predictions.
- Communicate scientific procedures and explanations.
- Use mathematics in all aspects of scientific inquiry.

Structure and function of living systems
- Living systems at all levels of organization demonstrate the complementary nature of structure and function.
- All organisms are composed of cells, the fundamental unit of life.
- Cells carry carry on many functions needed to sustain life.
- Specialized cells perform specialized functions in multicellular organisms.

Reproduction and heredity
- Reproduction is a characteristic of all living systems.
- In many species, females produce eggs and males produce sperm. An egg and sperm unite to reproduce.
- Every organism requires a set of instructions for specifying its traits. Heredity is the passage of these instructions from one generation to another.
- The characteristics of an organism can be described in terms of a combination of traits.

Regulation and behavior
- All organisms must be able to obtain and use resources, grow, reproduce and maintain stable internal conditions while living in a constantly changing external environment.
- Behavior is one kind of response an organism can make to an internal or environmental stimulus.
- An organism's behavior evolves through adaptation to its environment.

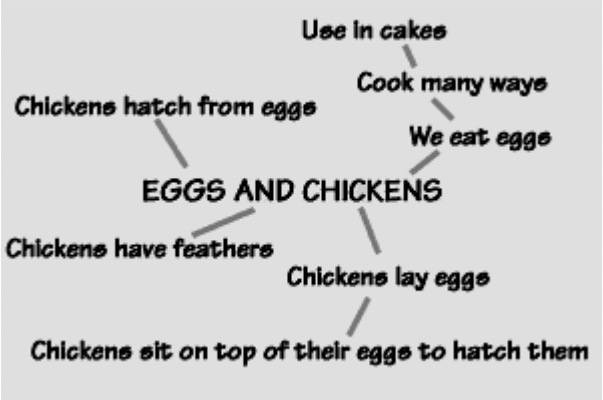
Abilities of technological design
- Identify appropriate problems.
- Design a solution or product.
- Implement a proposed design.
- Evaluate designs or products.
- Communicate the process of technological design.

Part I: Preliminary discussion: What do you know?

1. What do you know about eggs, chickens & hatching?

- Discuss what the students know. You can create charts as a group project, as a class project or as individual exercises.

Sample chart



You may want to include:

1. Physical characteristics of chickens
(colors, size, wings, feathers, feet, etc.)

2. Physical characteristics of eggs
(color, size, shape, shell, internal parts, etc.)

3. Uses of chicken & eggs
(food, decorations, etc.)

Vocabulary

lay	brood	fowl	class
hatch	embryo	poultry	breed
pip	egg tooth	rooster	variety
egg	development	chicken	bantam
beak	fertilized	hen	comb
yolk	chick	down	shanks
white	nest	feathers	wattles
shell	clutch	wings	

- Color & label the parts of a chicken

- Make a chicken collage – Find pictures of different chicken breeds.

Chickens are not all the same. They are grouped by class, breed and variety. There are also two sizes of chickens: standard and bantam. Bantams being one third to one-fifth the size of standard chickens. The American Poultry Association www.ampltya.com recognizes over 300 breeds of chickens.

2. What do you know about incubation?

Eggs have been incubated by artificial means for thousands of years. Both the Chinese and the Egyptians are credited with originating artificial incubation procedures. The Chinese developed a method in which they burned charcoal to supply the heat. They also used the hot-bed method in which decomposing manure furnished the heat. The Egyptians constructed large brick incubators which they heated with fires right in the rooms where the eggs were incubated.

Over the years incubators have been refined and developed to the point where they are almost completely automatic. The greatest development has occurred in the 20th century.

Modern commercial incubators are heated by electricity, have automatic egg turning devices, and are equipped with automatic controls to maintain the proper levels of heat, humidity, and air exchange. Present-day commercial incubators vary in capacity from a few thousand to many thousands of eggs, and they have made possible the development of modern hatcheries which produce almost 100 percent of all the chickens grown in this country.

- Explain to students that during incubation embryos must have certain things to help them develop:

    1. Warmth
    2. Turning
    3. Ventilation
    4. Humidity

- Discuss methods of supplying & regulating heat, humidity & turning comparing a hen and an incubator. Have students identify factors which can keep eggs from hatching.

- You may wish to set up the Mini Advance incubator and fill out the checklist provided with the students as an exercise on how to follow instructions.

- Have students play the Egg Game individually or in small groups. Each student or group starts with 24 paper eggs. The students flip a coin to move one or two spaces (see game board). The students keep track of their eggs throughout the game. Lost eggs are placed in an envelope. The winners are the ones with most eggs at the end of the game. At the end of the game you can ask students which of the hazards are caused by people and what can be done to protect the eggs.

<u>Additional vocabulary</u>

fan	membrane	candling
temperature	sac	turning
hygrometer	moisture	humidity
incubator	wet bulb thermometer	thermostat
heater	water pan	thermometer

- Teach students how to read thermometers, how to convert from Celsius to Fahrenheit and distribute the Daily incubation chart for them to record temperature, humidity, number of eggs set, clear & hatched.

- With older students you may also want to weigh the eggs the day they are set and then 3 or 4 times during incubation and graph the results as detailed in the Brinsea Mini Advance incubator instructions in the section “Determining correct humidity setting – monitoring egg weight loss”.

- You can post a job list assigning students to check temperature, humidity, water and later feed, water, clean the brooder enclosure & help dispose of the chicks (birth announcements to distribute to other classes and take home).

Incubation Check List

Obtaining and storing eggs

- ☐ Order fertile eggs from hatchery or breeding farm.
- ☐ Store eggs in cool (50°F/10°C), damp conditions for no longer than 10-14 days.
- ☐ Turn stored eggs daily.
- ☐ Discard cracked and heavily soiled eggs if possible. DO NOT wash eggs unless necessary.
- ☐ Just before setting in the Brinsea Mini Advance incubator allow the eggs to warm to room temperature.

Equipment set up

When you receive your Brinsea Mini Advance Classroom Pack:

- ☐ Read the instructions manual carefully
- ☐ Place the Mini Advance incubator on a flat surface.
- ☐ Set it up away from drafts, direct sunlight and traffic path.
- ☐ Allow the incubator to run for a few hours to stabilize the temperature before you set the eggs and begin incubation.
- ☐ Maintain room temperature between 68 and 77°F (20 and 25°C).
- ☐ Fill one of the water pots in the bottom of the Mini Advance incubator.
- ☐ Using the menu of the Mini Advance set the day countdown to the correct incubation period e.g. 21 days for chicken.

Incubation

- ☐ Set the eggs on their side in the pockets of the egg turning disk ensuring the disk is ribs side up.
- ☐ To avoid week-end hatches set your eggs on a Tuesday or Wednesday.
- ☐ Check the water level every 3 days. Top up with water at room temperature.
- ☐ Check temperature daily.
- ☐ Ensure nothing impedes the turning movement of the eggs e.g. eggs rubbing together or too large for the pockets of the turning disk.
- ☐ Candle the eggs every 3 days with the Brinsea OvaScope supplied to reject clear, infertile eggs or dead in shell embryos after day 9 to avoid bacterial contamination. Observe the size of the air cell and adjust humidity accordingly.

Pre-Hatching- Day 19

- ☐ Check that the egg turning has automatically stopped 2 days prior to hatch day and remove the egg disk from the Mini Advance incubator.
- ☐ Lower temperature to 97°F (36°C).
- ☐ Ensure the water pots are full to above the division between them. Humidity needs to be high.

Hatching

- ☐ Do not open the Mini Advance incubator during hatching . This would drastically reduce humidity endangering the chicks.
- ☐ Do not remove the chicks from the incubator until they are dry and fluffy.
- ☐ Set up the Brinsea Eco Glow brooder and enclosure provided with the Classroom Pack and transfer the chicks to the brooder.
- ☐ Provide water and feed for the chicks.

After hatching

- ☐ Find good homes for your chicks within a couple of days.
- ☐ Clean your Mini Advance incubator and brooder with the Brinsea disinfectant provided.
- ☐ Run incubator for 2 days to allow equipment to dry before putting away for next year.

Converting Celsius to Fahrenheit

Temperature is measured in degrees (°) using a thermometer. There are three temperature scales used today. The Kelvin scale used by scientists and for astronomical temperatures, the Celsius scale used in most of the world and the Fahrenheit scale used in the United States, both to measure air temperature.

The Celsius scale (°C) was developed in 1742 by Anders Celsius, a Swedish astronomer. The zero point is set to the freezing point of water and 100 to the boiling point of water. The Celsius scale is often called Centigrade scale because of the 100 intervals between the defined points.

The Fahrenheit scale (°F), the first widely used temperature scale, was developed in 1714 by Daniel Gabriel Fahrenheit, a German physicist. The number 32 was set at the freezing point of water and 212 at the boiling point of water, the interval between the two points being divided into 180 equal parts.

To convert Fahrenheit temperatures to Celsius:
Subtract 32 from the Fahrenheit temperature and multiply by 5/9.

To convert Celsius temperature to Fahrenheit:
Multiply the Celsius temperature by 9/5 and add 32.

Convert the following temperatures and match them:

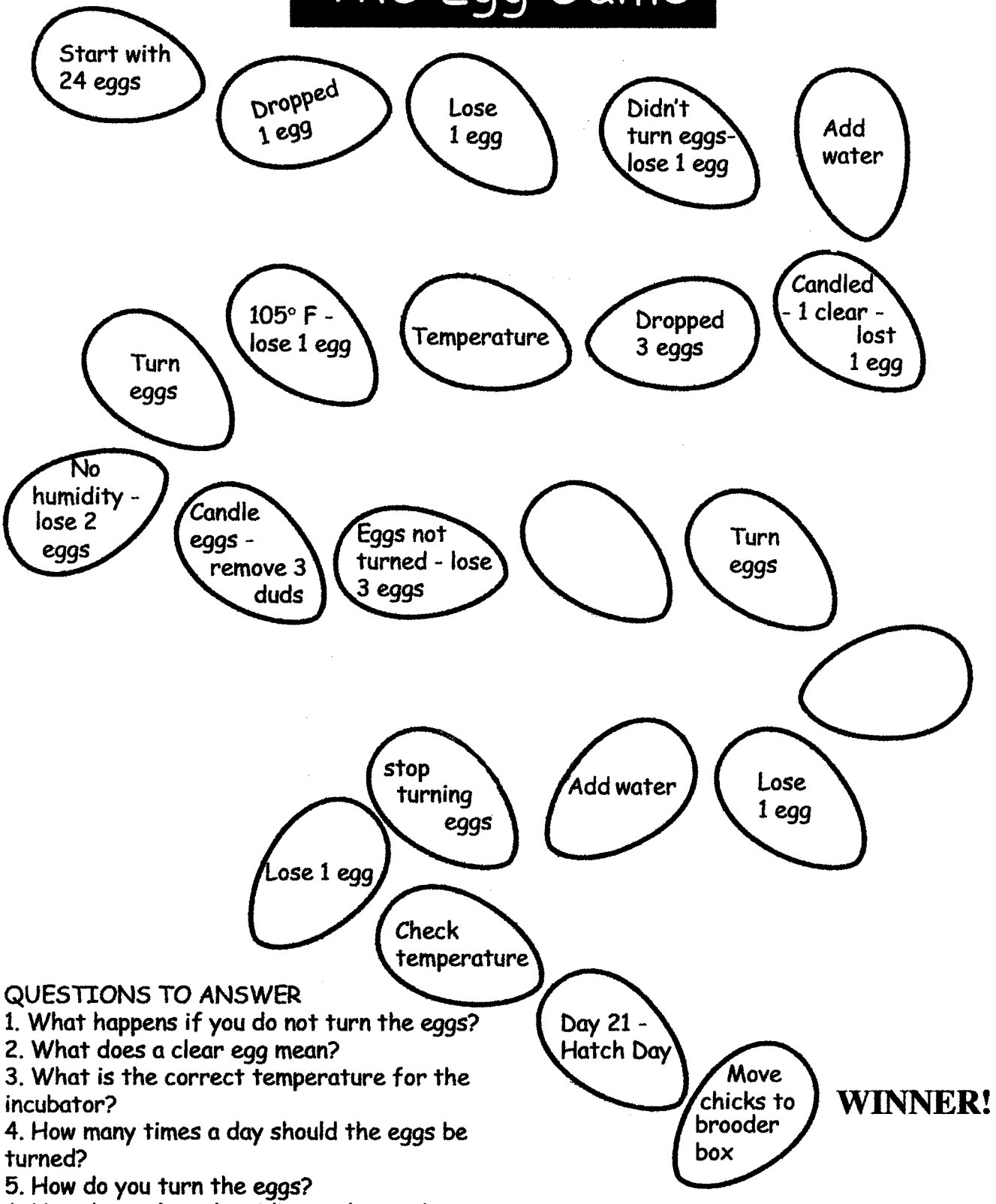
37.5 °C	Healthy Hen Body Temperature
98.6 °F	Comfortable Room Temperature
21.1 °C	Correct Incubator Temperature
107 °F	Average Human Body Temperature

Daily Incubation Chart

	# of eggs set	# of eggs clear	# of eggs hatched	Room Temp.	Incubator Temp.	Water checked	Turning checked	Remarks
Day0*								* Count Day 0 as the day eggs are set
Day 1								
Day 2								
Day 3								
Day 4								
Day 5								
Day 6								
Day 7								
Day 8								
Day 9								
Day 10								
Day 11								
Day 12								
Day 13								
Day 14								
Day 15								
Day 16								
Day 17								
Day 18								
Day 19							**DO NOT TURN!**	
Day 20							**DO NOT TURN!**	
Day 21							**DO NOT TURN!**	

The Egg Game

START



WINNER!

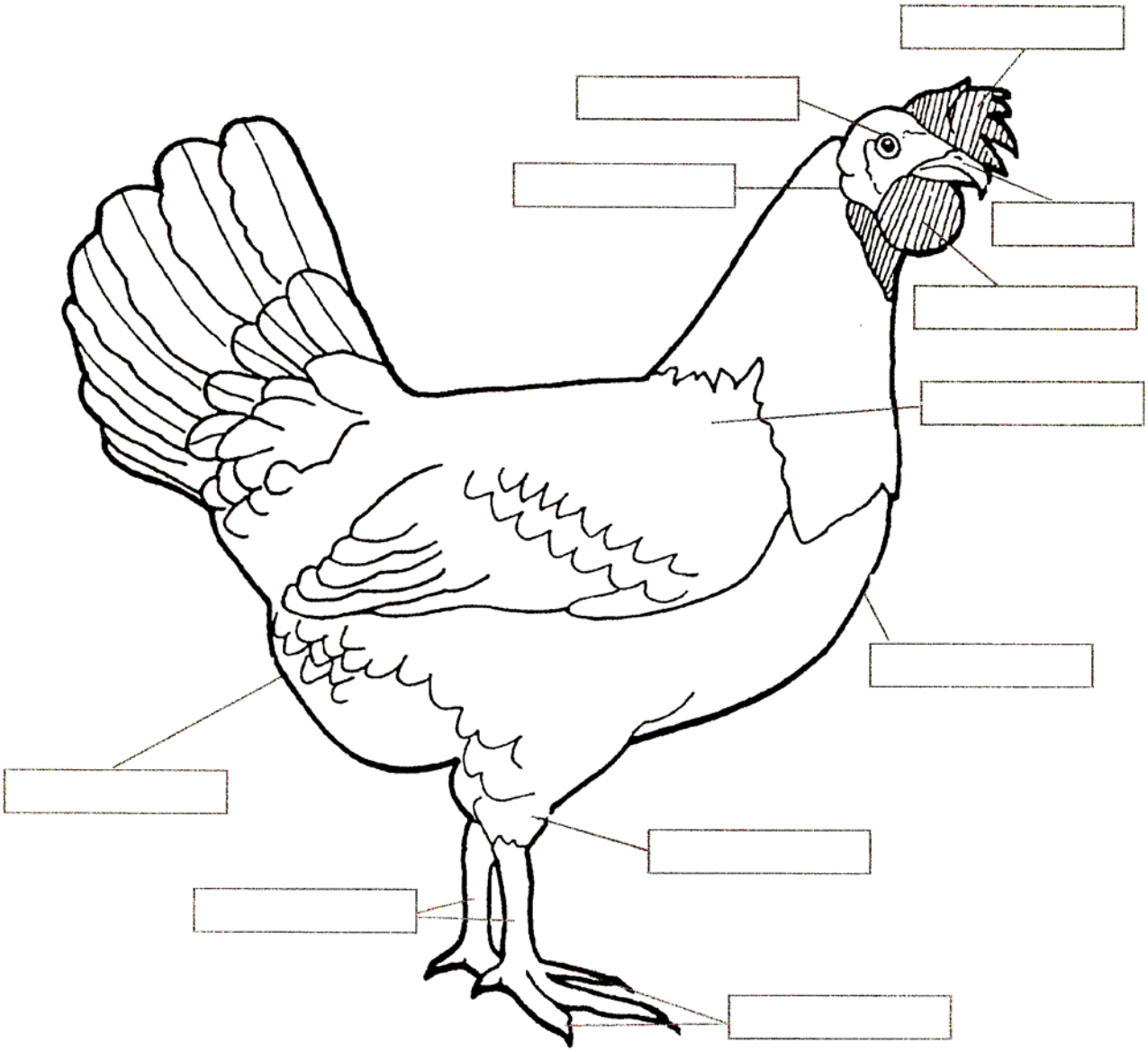
QUESTIONS TO ANSWER

1. What happens if you do not turn the eggs?
2. What does a clear egg mean?
3. What is the correct temperature for the incubator?
4. How many times a day should the eggs be turned?
5. How do you turn the eggs?
6. How do you keep humidity in the incubator?
7. Should eggs be rotated in the incubator?
8. What is candling?
9. When should you stop turning the eggs?

Heads moves 2 spaces.
Tails moves 1 space.

Parts of a Chicken

Color and label the parts of a chicken.

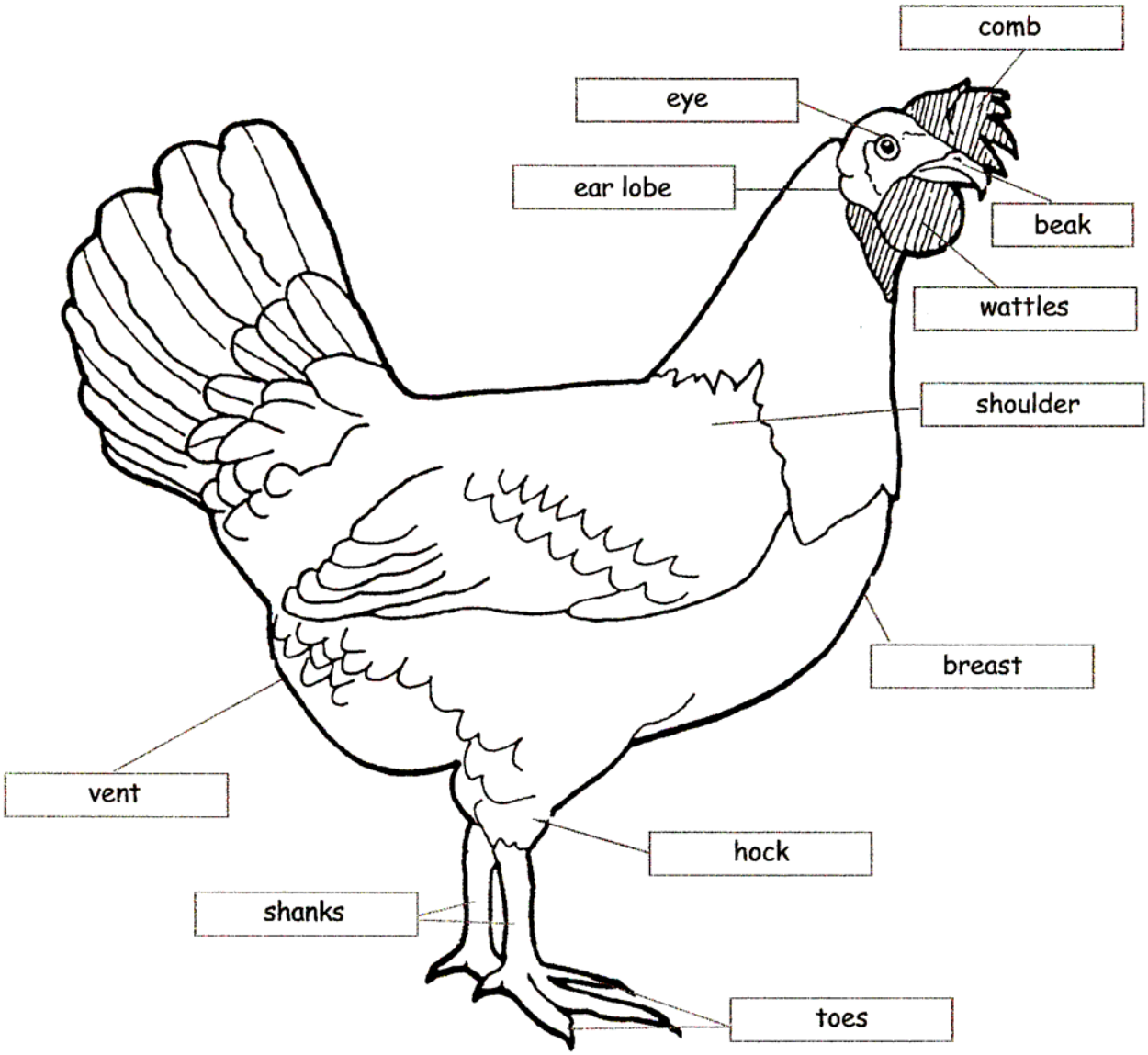


Use each word only once:

beak	breast	comb	ear lobe
eye	hock	shanks	shoulder
toes	vent	wattles	

Parts of a Chicken

Color and label the parts of a chicken.



Use each word only once:

beak	breast	comb	ear lobe
eye	hock	shanks	shoulder
toes	vent	wattles	

Part II: What is an egg?

Vocabulary

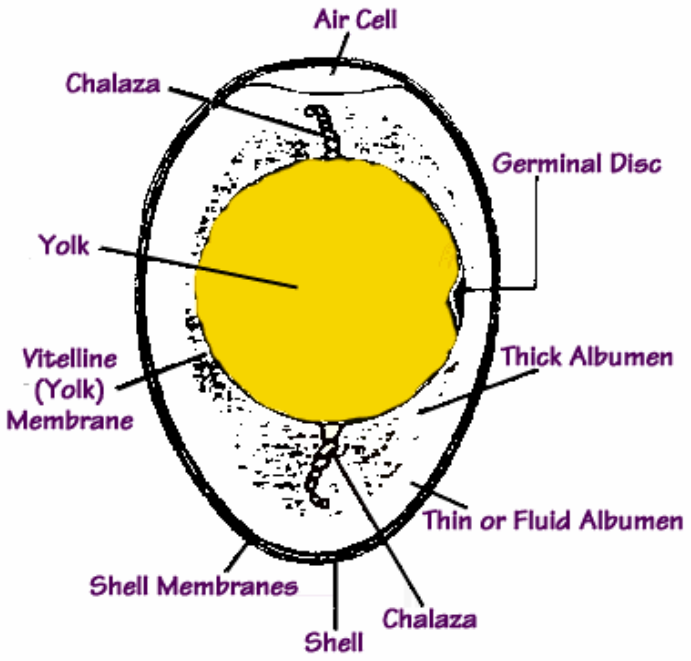
shell
porous
membranes
air cell
albumen
vitelline membrane
yolk
germinal disc or blastoderm
chalaza

Activities:

- Color & label each part of the egg
- Candle an egg with the Brinsea OvaScope supplied or crack a fresh egg and try to locate all the parts listed on the diagram.
- Visit the American Egg Board web site www.aeb.org. for further information and activities about egg nutrition, egg grading and sizing.

What is an egg

1. The structure of an egg



The egg is a highly complex reproductive cell, a tiny center of life. It protects and provides a complete diet for the developing **embryo** during the 21 day incubation period. It is also one of the most nutritious and versatile of human foods.

When the egg is freshly laid it is at the same temperature as the hen, about 107 °F (42°C) and fills the **shell** completely. As it cools to the temperature of its environment, the contents of the egg contract and form an **air cell** between the two **shell membranes**.

The air cell is usually located at the large end of the egg where the shell is most **porous**. The thousands of tiny holes in the shell called **pores** which allow the embryo to breathe are larger and more numerous at the large end than those at the small end and allow the air to enter the air cell easily. The chick punctures and breathes through his air cell just before hatching. The shell and its membranes protect the embryo and conserve the food and water supply in the egg.

The **germinal disc** or **blastoderm** from which the chick develops is attached to the **yolk**. Surrounding and protecting the germ cell and yolk is the colourless **vitelline membrane** and the white or **albumen** consisting of several layers. The albumen is a somewhat elastic, shock absorbing thick material with a high water content. The albumen and the yolk serve as food for the embryo during the incubation period. The yolk particularly contains a large amount of proteins, fats, carbohydrates, minerals and vitamins.

On opposite sides of the yolk are two twisted whitish cord-like objects known as **chalazae**. They support the yolk in the center of the albumen and serve as a rotating axis to keep the embryo on top of the yolk and therefore next to the heat of the hen's body.

2. Composition of an egg

An average size eggs weighs about 2 ounces (57 grams). Of this weight the shell constitutes 11%, the white 58% and the yolk 31%.

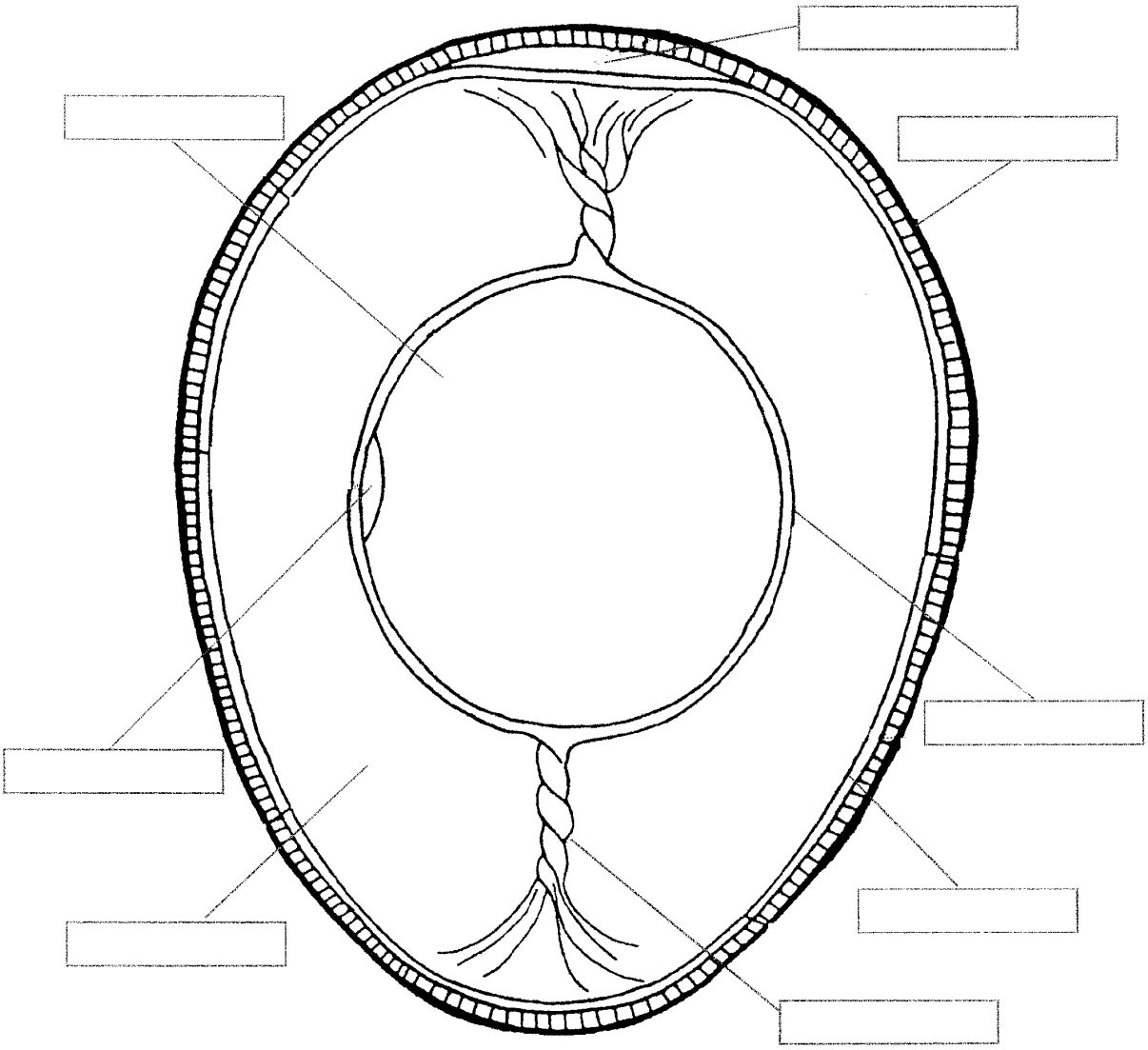
The composition of the edible portion is:

	Water	Protein	Fat	Other
Whole egg	74%	13%	11%	2%
White	88%	11%	0%	1%
Yolk	48%	17%	33%	2%

Eggs are especially valuable as a source of protein (about 0.25 ounces or 7 grams per egg) and fat which provides energy. Eggs contain vitamin A, B and D which are all necessary for growth. Eggs also contain a lot of minerals such as iron and phosphorus which are essential for building and maintaining strong bodies. But they are low in calcium which is mainly stored in the shell. They contain little or no vitamin C.

Egg Parts

Color each part of the egg a different color
and label each part of the egg.

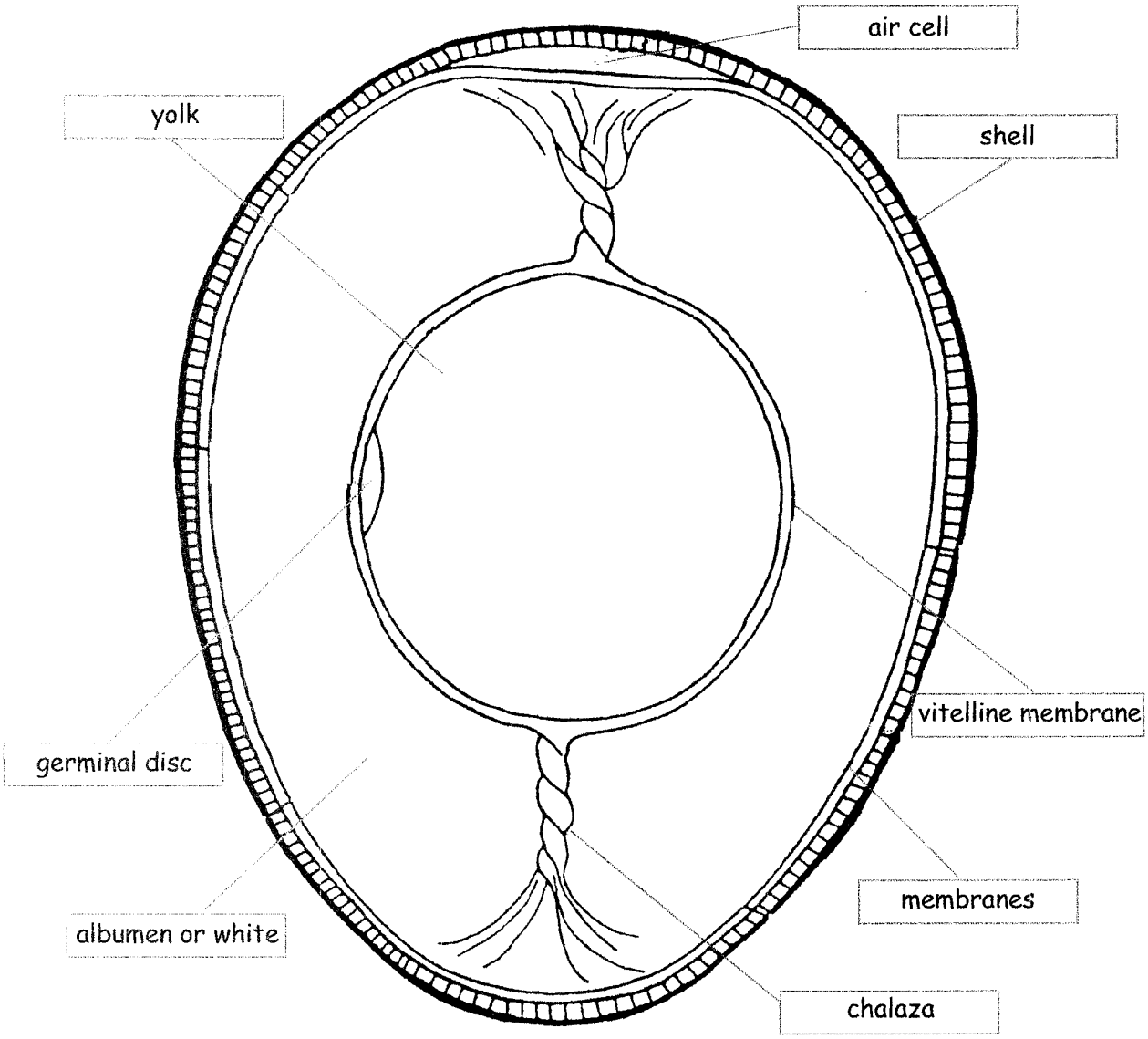


Use each word only once:

air cell	albumen or white	chalaza
germinal disc	membranes	shell
vitelline membrane	yolk	

Egg Parts

Color each part of the egg a different color and label each part of the egg.



Use each word only once:

air cell	albumen or white	chalaza
germinal disc	membranes	shell
vitelline membrane	yolk	

Part III: How hens lay eggs

Vocabulary

lay
fertilization
rooster
mating
sperm
ovum
reproductive cell/system
ovary
ovulation
oviduct
follicle
cuticle
gland
cell division
abdomen

Activities:

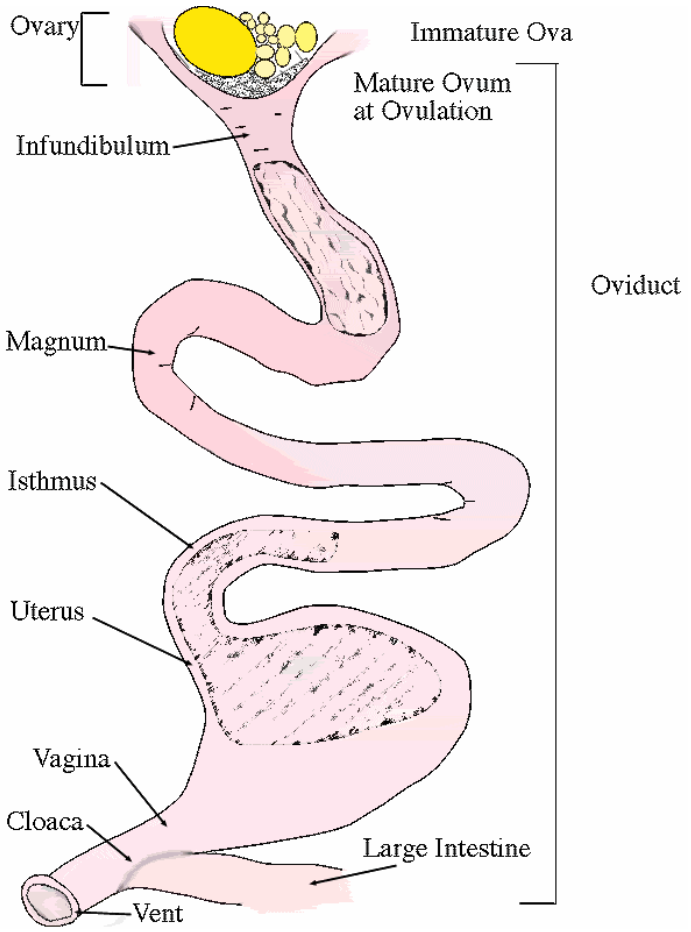
- Which egg is fertile
- Crossword puzzle

How hens lay eggs

1. How the egg is fertilized

A hen can produce an egg without mating. Such an egg while edible, is not **fertile** and will not hatch. If a rooster mates with and fertilizes a hen, the male reproductive cell or **sperm** swim up the **oviduct** and is stored in a gland in the **infundibulum**. When a yolk is released one sperm penetrates the germinal disc and unites with the female reproductive cell, the **ovum**, to form a single cell that can develop into an embryo. This is called **fertilization**. This egg is fertile and can hatch. When an egg is opened and placed in a dish you can see a light round spot on top of the yolk. This is the germinal disc but at the time of lay it is hard to tell whether or not it is fertile.

2. Hen reproductive system



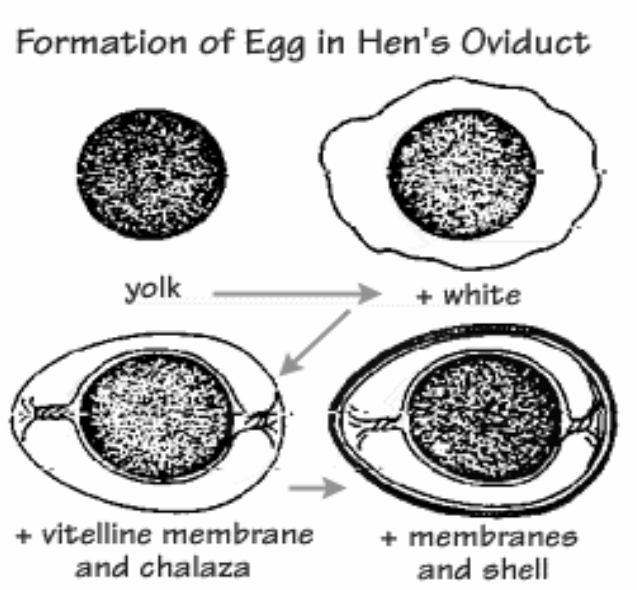
The egg is formed by a **reproductive system** composed of an ovary and an oviduct.
An **ovary** looks like a cluster of grapes and may contain up to 4,000 small eggs or **ova** (singular ovum) which can develop into yolks. Each ovum is attached to the ovary by a thin membrane sac or **follicle**.

The **oviduct** is a large, coiled tube located in the left side of the hen's abdomen. In this oviduct all parts of the egg, except the yolk, are formed.

It is divided into 5 distinct regions:

- infundibulum
- magnum
- isthmus
- uterus
- vagina

3. How the egg is formed



The yolk is formed in the follicle by the deposition of continuous layers of yolk material in rings like those of a tree. 99% of the yolk material is formed within 7-9 days before the egg is laid. The germinal disc of a developing yolk contains a single cell, which after fertilization develops into a chick. The germinal disc remains on the surface of the yolk throughout yolk formation. When the ovum has accumulated enough yolk to grow a chick, it is released from the ovary. This is called **ovulation**.

The yolk is kept intact by the **vitelline membrane** surrounding it and moves through the **infundibulum** where **fertilization** of the ovum follows almost immediately.

Sperm cells from the male are stored in **glands** or nests in the infundibulum and are released when the yolk passes by. A sperm cell must enter the thin vitelline membrane and reach the female cell to complete fertilization. The newly formed cell begins to divide immediately and continues until a tiny cluster of whitish cells called the **blastoderm,** appears on the yolk.

The yolk then quickly enters the **magnum** where the dense portion of the albumen is added. The shape of the egg is largely determined in this section.

The **isthmus** is smaller in diameter than the magnum. It is here the two shell membranes form. The shell membranes loosely contain the yolk and dense albumen until the rest of the albumen is added in the uterus.

The chalazae and shell are also added in the **uterus**. It takes about 20 hours for the egg shell to form. If the hen lays brown eggs, the brown pigments are added to the shell in the last hours of shell formation.

In the last portion of the oviduct, the **vagina**, a thin coating called **cuticle** is applied to the shell to keep harmful bacteria from entering the egg shell pores. The egg passes through the oviduct small end first but is laid large end first. In the vagina the egg is turned horizontally just before laying through an opening called the **cloaca**.

3. How the embryo begins to develop before the egg is laid and incubated

The embryo starts to develop even while the rest of the egg is being formed. About 3 hours after fertilization, the newly formed single cell divides and makes 2 cells, then 4, 8, 16, 32, etc. Cell division will continue until the egg is laid or if it is kept warmer than 67°F/19°C.

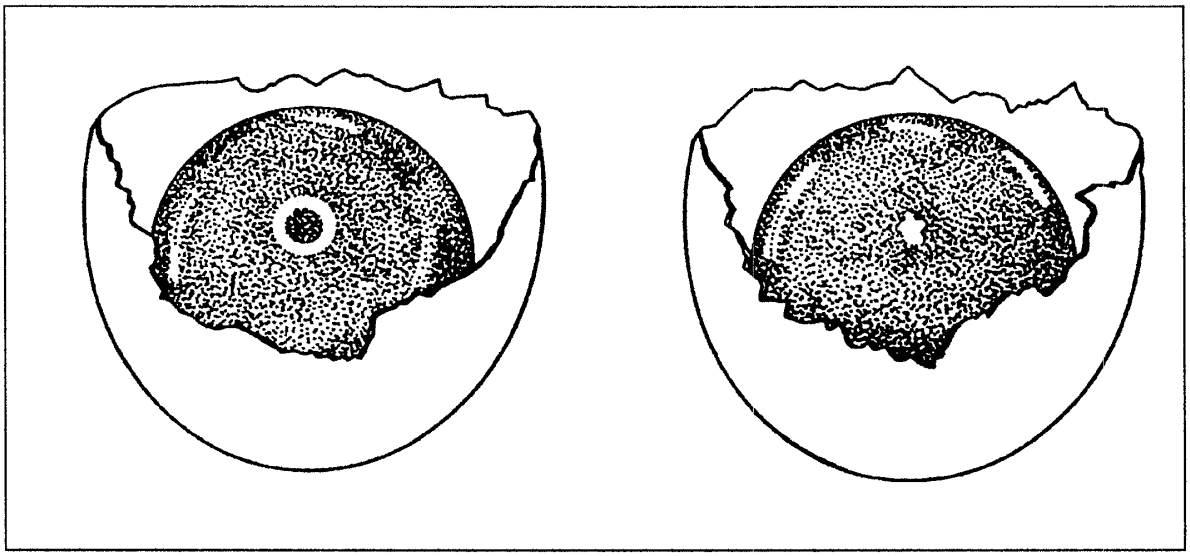
At first all the cells are alike but as the embryo develops cell differences are observed. They divide into groups of specialized function. Some become vital organs such as a heart or a lung, others a wing or a leg.

When the egg is laid and its temperature drops, the embryo stops growing until it is incubated by the hen or in an incubator like the Brinsea Mini Advance in your classroom.

Which Egg Is Fertile?

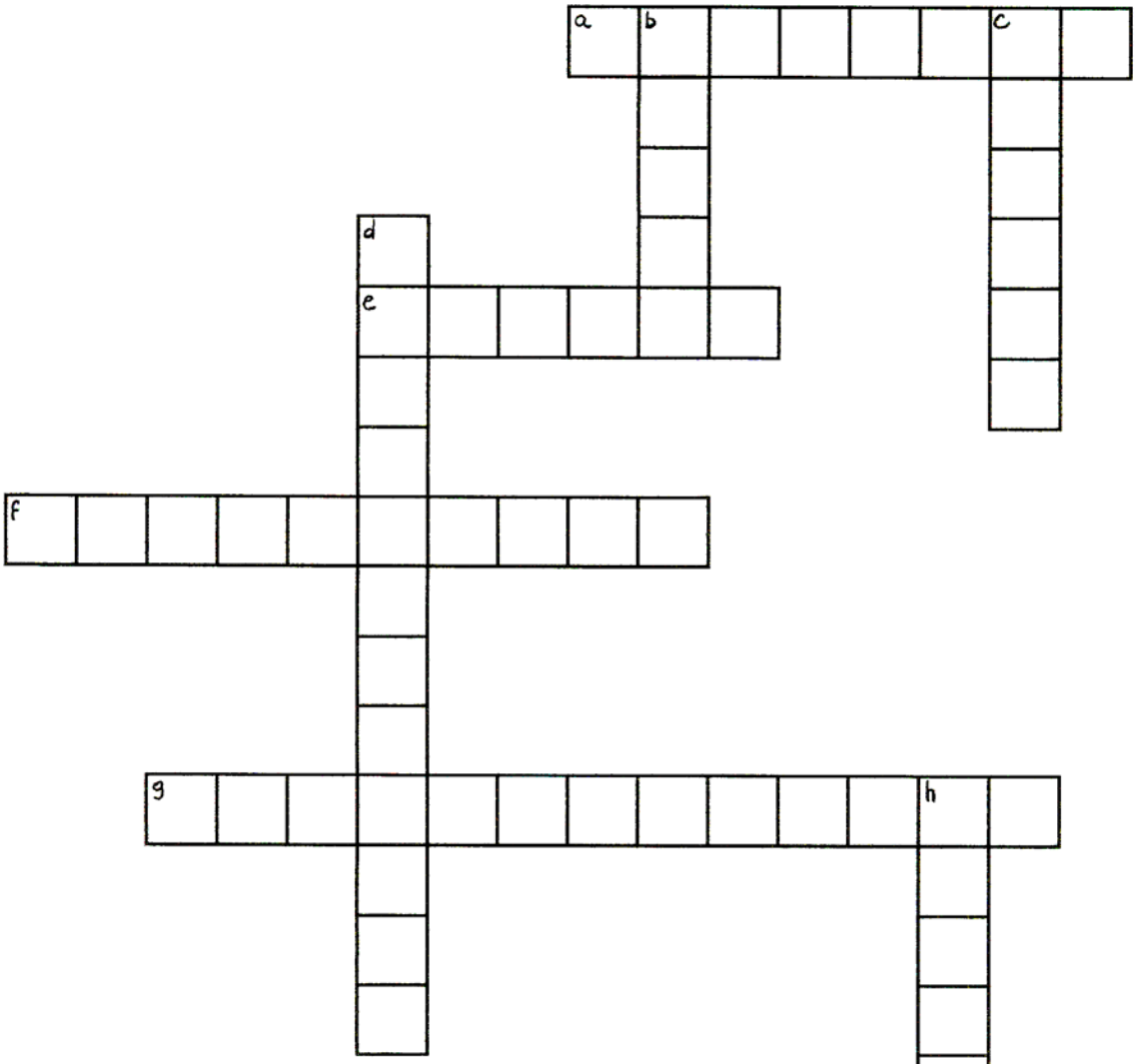
When fertile eggs are incubated by either a hen or in an incubator, they grow.
What is needed to make an egg fertile?

Look at the picture below and mark the fertile egg.



How do you know that the egg you have marked is fertile? Explain.

Crossword Puzzle



a. **(across) What do you call the sac which holds the yolk until it matures and is released?**

b. **(down) What do you call the organ of the hen which forms the yolks?**

c. **(down) What do you call the action of a hen pushing an egg out?**

d. **(down) What do you call the process of continuing the species?**

e. **(across) What do you call an unborn chick?**

f. **(across) What do you call a group of fertilized cells which develops on the yolk?**

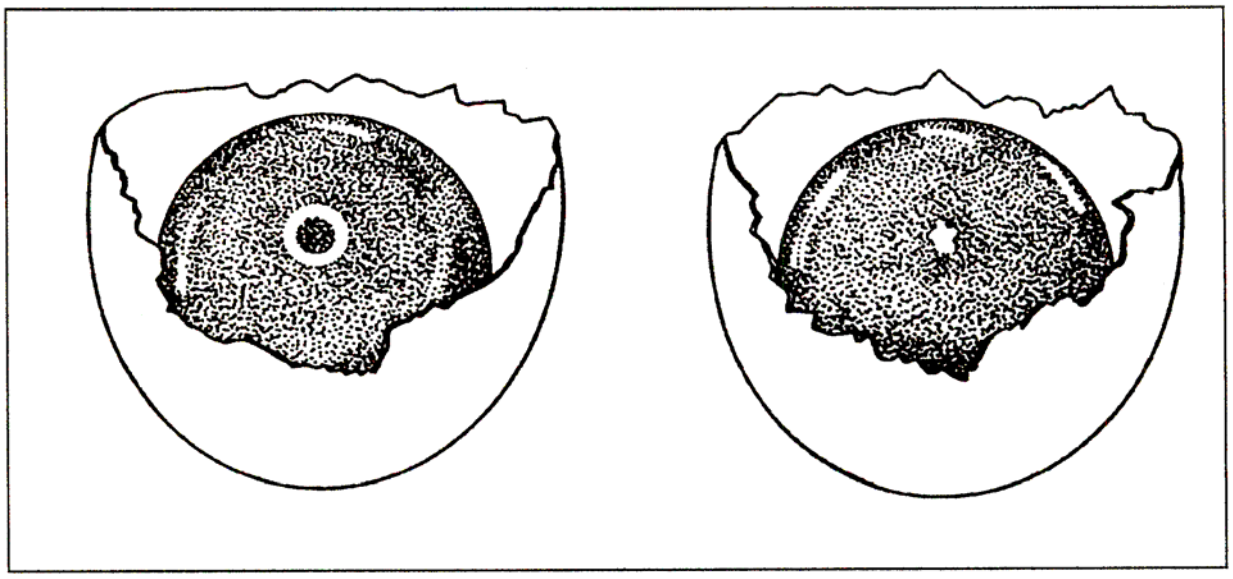
g. **(across) What do you call the union of a male cell with a female cell?**

h. **(down)What do you call the organ of the hen which puts the albumen, membranes and the shell around the yolk?**

Which Egg Is Fertile?

When fertile eggs are incubated by either a hen or in an incubator, they grow.
What is needed to make an egg fertile?

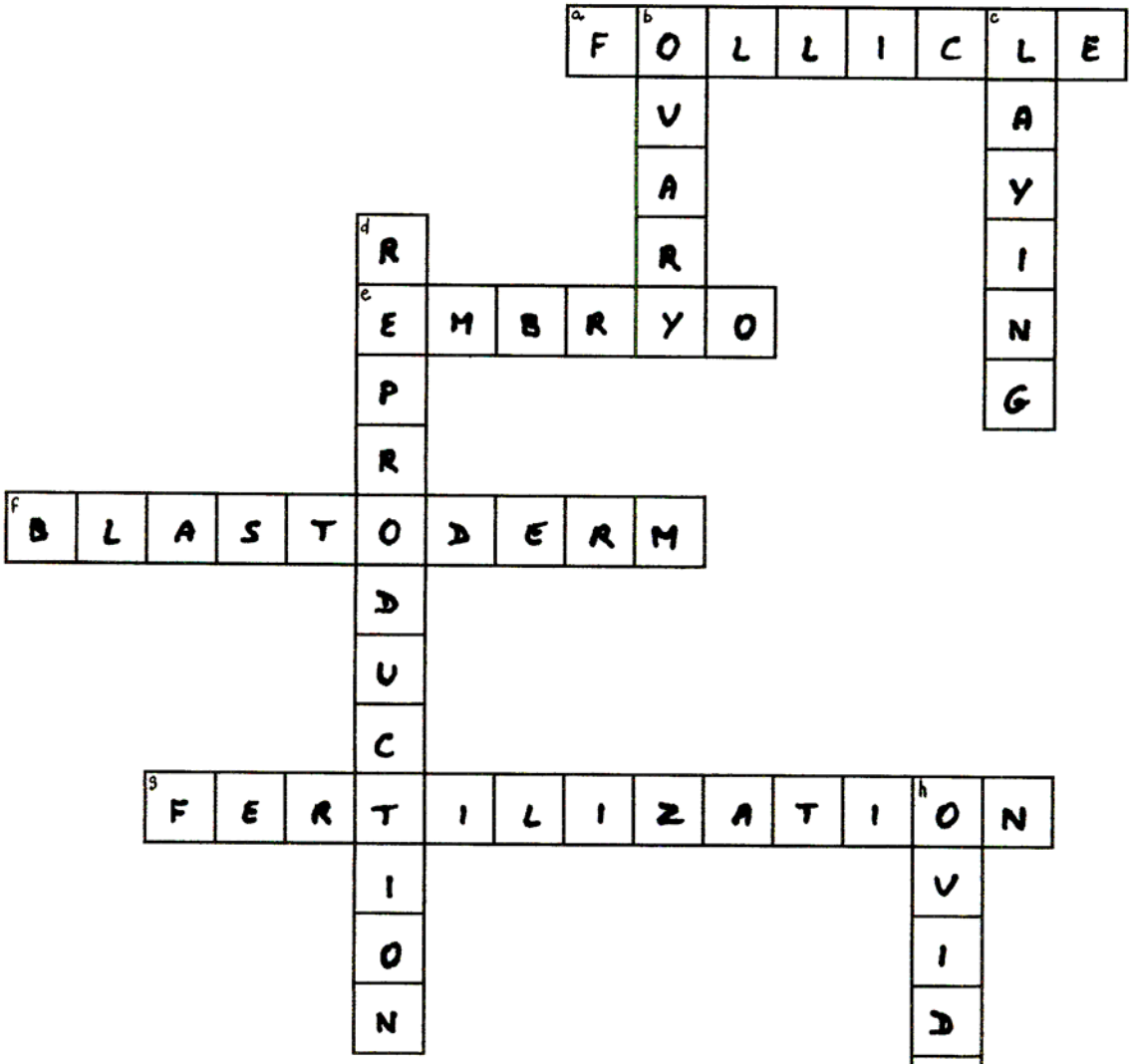
Look at the picture below and mark the fertile egg.



How do you know that the egg you have marked is fertile? Explain.

The egg on the left. The germinal disc is larger in the fertile egg as compared to the infertile egg. Cell division has occurred in the fertile egg. The fertile egg has an enlarged circle or donut. The germinal disc is small in the infertile egg.

Crossword Puzzle



a. (across) What do you call the sac which holds the yolk until it matures and is released?

b. (down) What do you call the organ of the hen which forms the yolks?

c. (down) What do you call the action of a hen pushing an egg out?

d. (down) What do you call the process of continuing the species?

e. (across) What do you call an unborn chick?

f. (across) What do you call a group of fertilized cells which develops on the yolk?

g. (across) What do you call the union of a male cell with a female cell?

h. (down)What do you call the organ of the hen which puts the albumen, membranes and the shell around the yolk?

Part IV: How a chick develops day by day during incubation

Vocabulary:

extraembryonic membranes
yolk sac
amnion
allantois
vitelline system
circulatory system
arteries
veins
capillaries
hemoglobin
plasma
atria
ventricles
blood cells
organ
bone marrow
cartilage
ossification
air sacs
inhale
exhale
pneumatized
alveoli
minerals
nutrients
egg-tooth
pipping
hatching
metabolic rate
cell

Activities:

- Observing an Embryo – if possible conduct the activity day 3 or 4 of incubation without students having prior access to graphics or real embryos.

- Weigh eggs and plot a chart of weight loss as detailed in the Brinsea Mini Advance instructions in the section "Determining correct humidity setting – monitoring egg weight loss".

- Have the students create a collage or draw a poster of embryonic development to be displayed in the school

- With older students you may want to shell-window eggs or make embryo sets by opening eggs and preserving embryos in alcohol. For instructions on such embryology projects you can refer to the "Avian embryo" on the Mississippi State University web site: www.msstate.edu/dept/poultry/avianemb.htm

- Watch a chick hatch and describe what you see. Compare what you expected to see and what you actually saw.

How a chick develops day by day during incubation

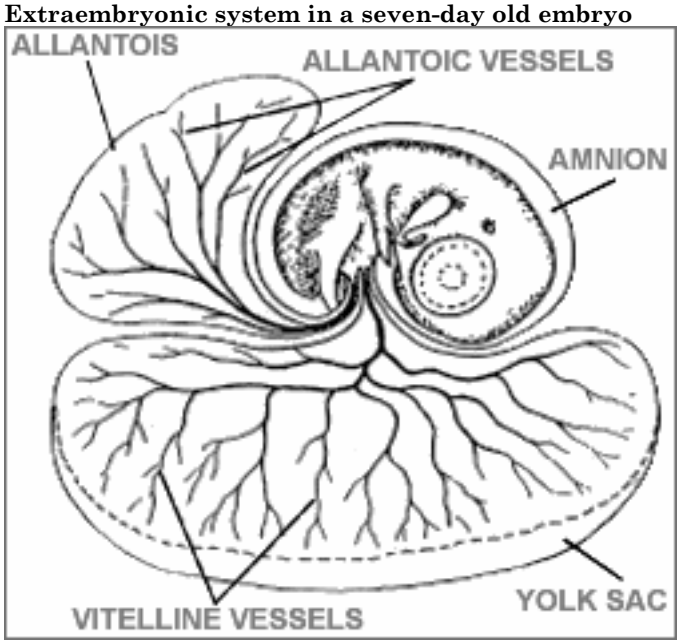
A growing embryo is very small and at first changes cannot be seen without a microscope but the following pictures show you what you would see if you cracked open a developing egg every day.

Day 1

18 hours – the digestive system starts to appear
20 hours – the vertebral column starts to appear
21 hours – the nervous system and brain begin to form
22 hours – the head begins to form
23 hours – the extraembryonic blood systems begin to form
24 hours – the eyes begin to form

Focus on the extraembryonic blood systems

Extraembryonic system in a seven-day old embryo



During incubation the embryo needs to breathe, feed and be protected. **Extraembryonic membranes** are membranes outside the embryo's body which make this possible.

The extraembryonic membranes are :
- the yolk sac
- the amnion
- the allantois

None of these membranes become a part of the chick. They stop functionning when the chick punctures the air cell and starts to breathe on its own.

The **yolk sac** surrounds the yolk and draws food from it for the embryo. The **amnion** is a transparent sac filled with a colorless fluid in which the embryo floats that protects it from shocks and prevents it from drying out.

Respiration is made possible by the **allantois**. As it grows with the chick, the allantois is pressed against the egg shell where it can easily absorb **oxygen** passing through the pores of the egg shell in exchange for **carbon dioxide**. The allantois also stores waste, absorbs albumen used as food by the embryo and absorbs **calcium** from the shell for bone construction. For the first 10 days the chick can absorb a sufficient amount of calcium from the yolk but as the formation of bones begins to accelerate the chick must take calcium from the egg shell.

There are two distinct extraembryonic blood systems: Blood vessels in the allantois called **allantoic vessels** which bring oxygen to the embryo and take carbon dioxide away. The other blood system made of **vitelline vessels** brings nutrients from the yolk to the embryo. During the first 3 days of its life, the chick relies on the vitelline vessels to also absorb oxygen but by the 4th day the chick needs more oxygen than can be supplied by only the vitelline system and begins to rely on the allantois which will soon take over respiration.

Day 2

25 hours – the heart begins to form
35 hours – the ear pits begin to form
37 hours – the amnion starts to appear
42 hours – the heart starts to beat
46 hours – the throat begins to form

Focus on the heart and the circulatory system

1. What is the circulatory system and what does it do?

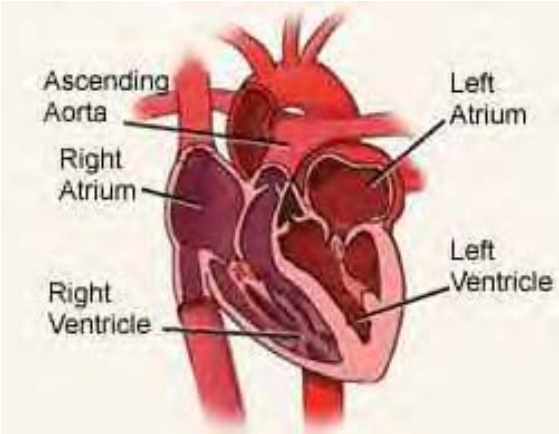
The **circulatory system** is like a circular network of roads on which traffic travels in only one direction around the body. Every part of the body is connected through the network of **blood vessels**. The large blood vessels carrying blood away from the heart are called **arteries** and the vessels carrying blood to the heart are called **veins**. Inside organs, the vessels branch into smaller and smaller vessels, the smallest of which are called **capillaries**.

The blood flowing in these vessels is composed of **blood cells** floating in a fluid called **plasma**. Red blood cells have a chemical called **hemoglobin** which is responsible for carrying oxygen from the lungs to the individual cells of the body. In return the hemoglobin trades its oxygen against carbon dioxide, a waste product and carries it back to the lungs to be expelled. The plasma is responsible for carrying all other nutrients (water, food, etc) to the cells and in return removing waste taking it to the skin, kidneys and other organs that specialize in removing waste from the body.

The circulatory system is also a cooling and heating system which maintains body temperature.

2. The heart as a pump

A human heart



Blood is kept moving along its circular route by the pumping action of the heart.
The heart consists of 4 **chambers**: the upper two chambers are the left and right **atria** and the lower two chambers are the right and left **ventricles**.

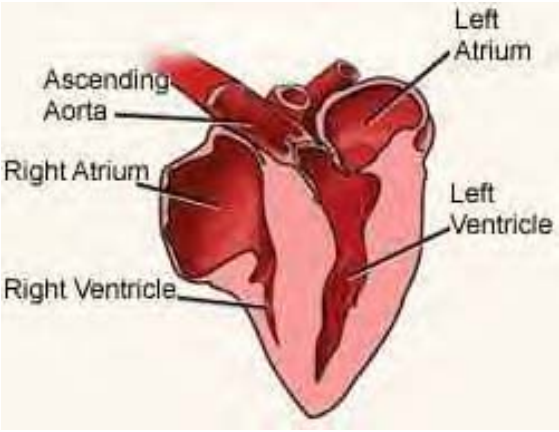
The right atrium and ventricle receive blood rich in carbon dioxide from the body and send it to the lungs where it will trade its carbon dioxide for oxygen. The left atrium and ventricle receive oxygenated blood from the lungs and pump it back into the body.

The ventricles have thick walls made up of **cardiac muscle**. This specialized type of muscle is only found in the heart. It is made in such a way that when it contracts it squeezes the heart and forces blood out of it.

The atria and ventricles are joined by **valves**. There are also valves between the ventricles and the arteries which they feed. The valves prevent blood from being forced back into the chamber from which it was expelled and keep the blood flowing in one direction.

3. Particularities of the chicken heart

A chicken heart



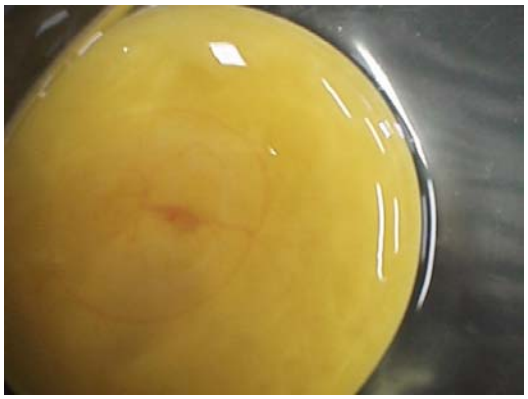
Birds have a much higher **metabolic rate** than humans. The average body temperature of a chicken is 106-113°F (41-45°C) compared to a human average body temperature of 98.6°F (37°C).

The pulse rate of a chicken can reach as high as 400 beats/minute. The chicken heart therefore has to work much harder than a human heart and is adapted to the increased stress placed on it.

The size of the heart in relation to the body is larger (about 0.8%) than in humans (about 0.6%).

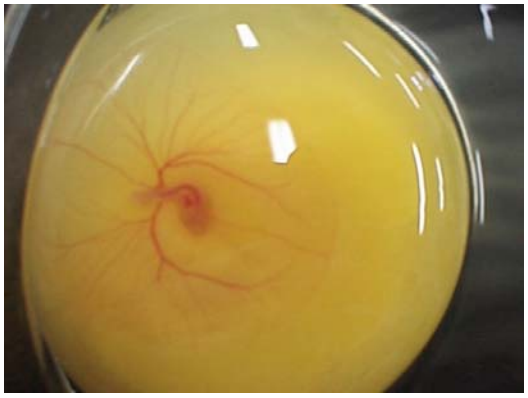
The inside walls of the atria and ventricles are much smoother than those of a human and the valves are much simpler. This reduces friction (rubbing) as the blood is pumped through and means less work. The ventricles have more muscle and less chamber space than those of a human.

Day 3



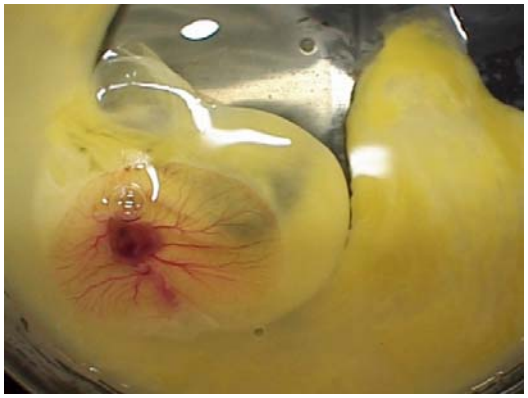
50 hours – the amnion begins to form
60 hours – the nose begins to form
62 hours – the legs start to appear
64 hours – the wings start to appear
70 hours – the allantois begins to form

Day 4



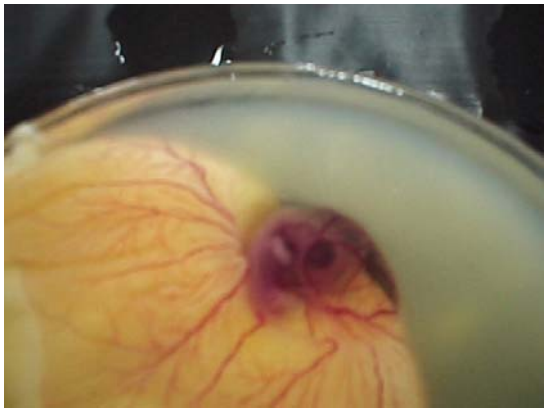
The tongue begins to form
The tail appears
The toes begin to form
Extra-embryonic circulation is fully functional

Day 5



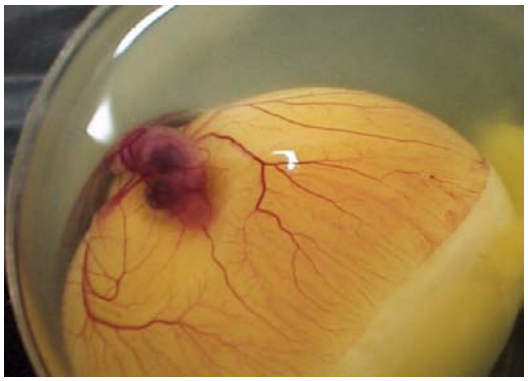
The crop begins to form
The bones of the legs begin to form
The sex of the chick is determined and its reproductive organs begin to form (ovary & oviduct for the female as studied in Part III)

Day 6



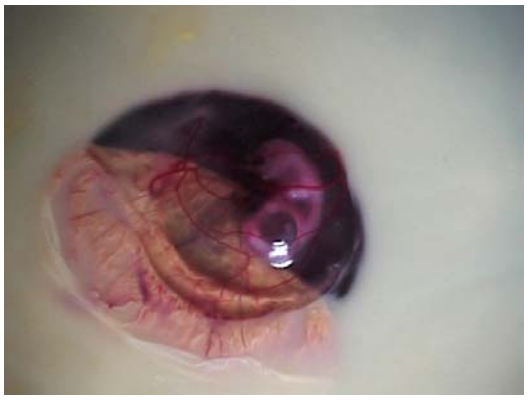
The beak and egg-tooth begin to form
The ribs start to appear
The gizzard begins to form
Voluntary movement begins

Day 7



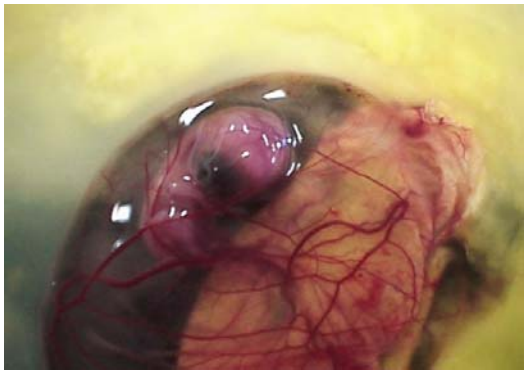
The wings bend at the elbow
and the leg at the knee
The toes are visible
The abdomen is bigger as
the intestine starts to loop

Day 8



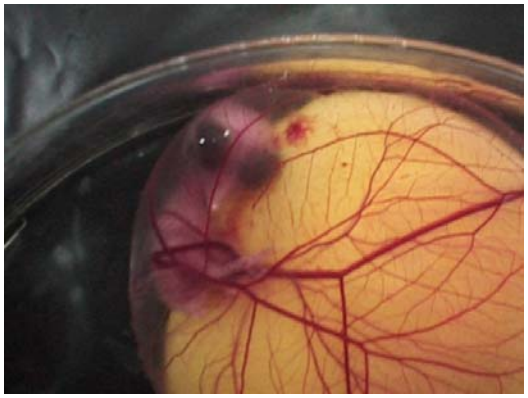
The feathers begin to form
The eye lids begins to form

Day 9



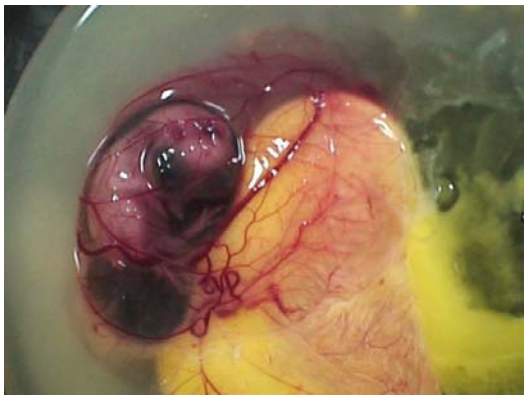
The mouth opening appears
The claws begin to form

Day 10



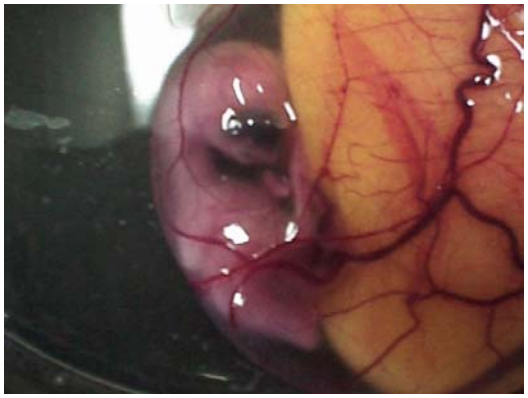
The beak starts to harden
The comb is visible
The flight feathers develop

Day 11



The toe claws begin to curve downwards
The bottom of the feet become padded
The chick begins to take calcium
from the eggshell

Day 12



Scales appear on the lower legs
The chick continues to grow and move

Day 13

Body fairly well covered with feathers
The left and right collar bones join
to form the wishbone

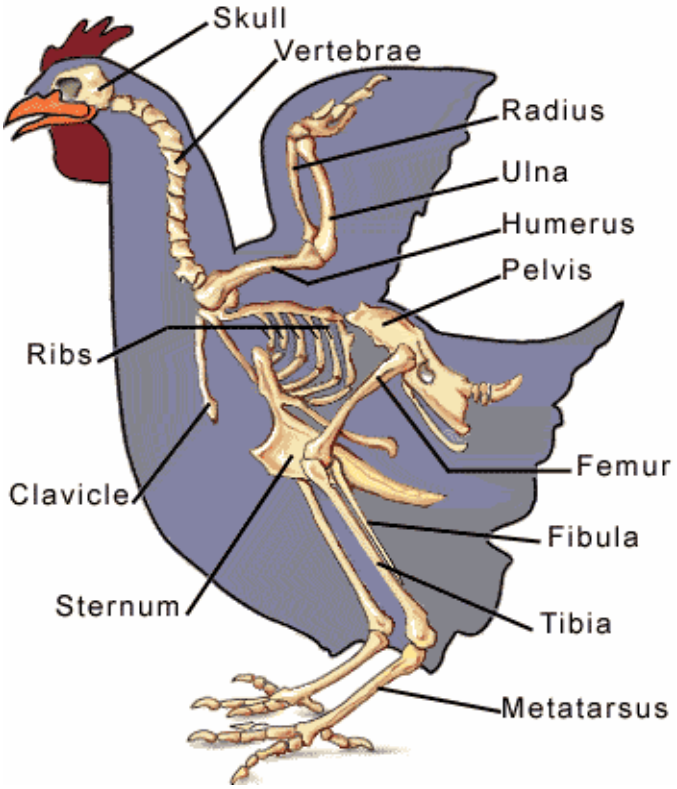
Day 14

The embryo turns its head towards
the large end of the egg
The skull and ribs have begun to ossify

Focus on bones and the skeleton

1. What are bones and what do they do?

Skeleton of an adult chicken



Bones are made of minerals, mostly calcium and phosphate. There are 3 types of **bone cells**: osteoblasts, osteocytes and osteoclasts. **Osteoblasts** are responsible for making the structure and then laying in the minerals. **Osteocytes** are responsible for feeding the bone and **osteoclasts** help shape the bones as they grow.

New bone is first created randomly and then reshaped in concentric layers like the rings of a tree. Bone can be either compact or spongy.
Compact bone on the outside provides strength, support and protection.
Spongy bone on the inside allow the bone to be lightweight and provide a space in which bone marrow can grow.
Bone marrow makes blood cells.

Bones provide structure, support and protection for most of the organs of the body. They also provide a framework for muscles to move. Bones store minerals such as calcium for the body to use when needed.

2. What is cartilage?

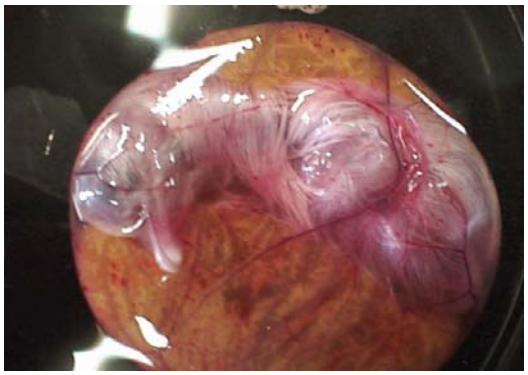
Cartilage is a strong but flexible material like hard rubber. In the embryo, most of the skeleton is first made of cartilage. As the embryo grows, the cartilage is replaced by bone. This is called **ossification**.

3. How are bones different in birds?

Bird bones contain **air sacs** and are said to be **pneumatized**. When a bird takes off for flight the exaggerated movement of the wings creates an air current which fills the air sacs within the bones and makes the bird light enough to fly. The bones do not become pneumatized until after the bird hatches.

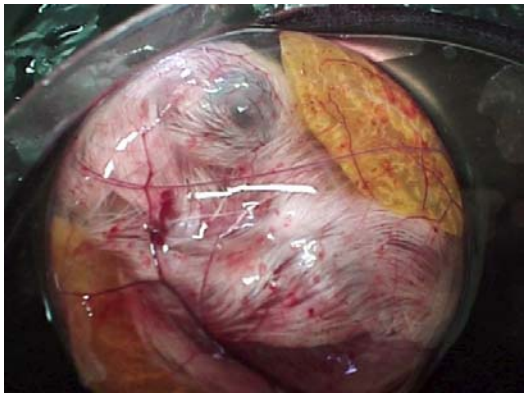
During the periods when a hen is laying many eggs, she stores extra calcium from her diet in her own bones which she uses to make egg shells. If the hen cannot get enough calcium in her diet to store extra calcium she will use calcium already in her bones. This will weaken her bones and may still produce a weak egg shell. The chick embryo relies on its shell for protection but also as a source of calcium once its bone begin to ossify on day 14.

Day 15



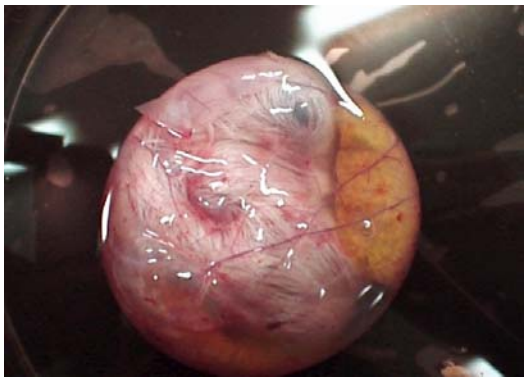
The scales, claws and beak are becoming firm

Day 16



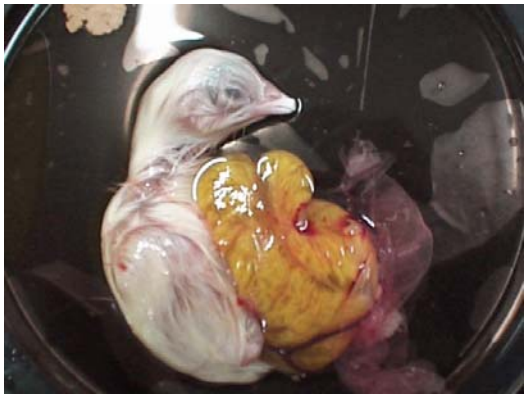
The chick is fully covered with feathers
The albumen is nearly gone and the yolk
is increasingly important as nourishment

Day 17



The chick turns its beak towards the air cell
and begins preparation for hatching

Day 18



The growth of the embryo is nearly complete
The amnion which protects the chick
begins to disappear

Day 19

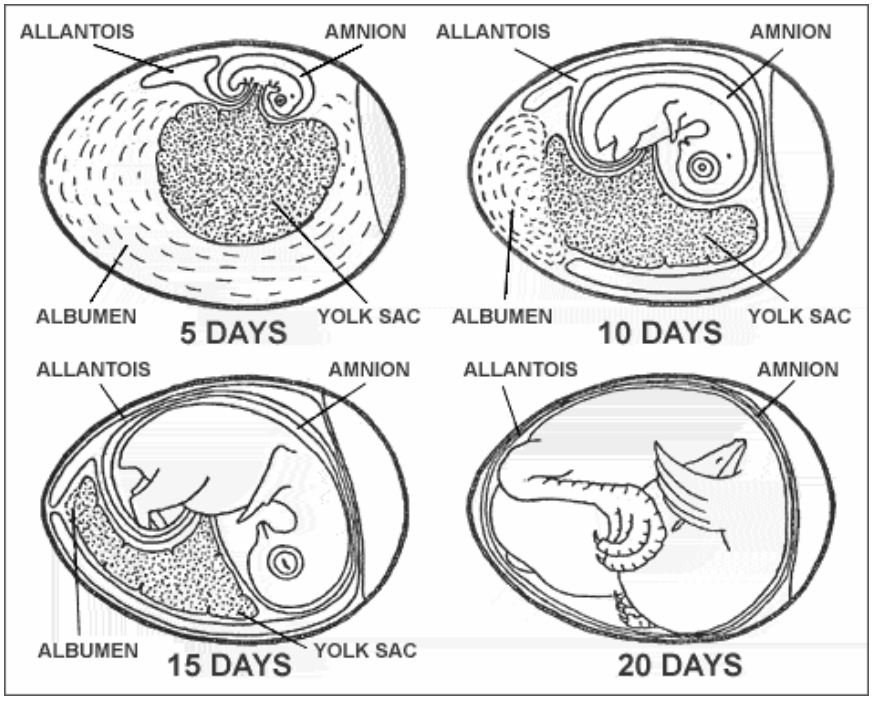
The yolk sac begins to enter the body
The chick occupies all the space in the egg except the air cell

Day 20

The yolk sac is completely drawn into the body
The beak breaks through the inner shell membrane
The lungs begin to function and to use the air cell for breathing
The allantois ceases to function and starts to dry up

Focus on the respiratory system. How birds breathe?

1. How the chick breathes inside the egg



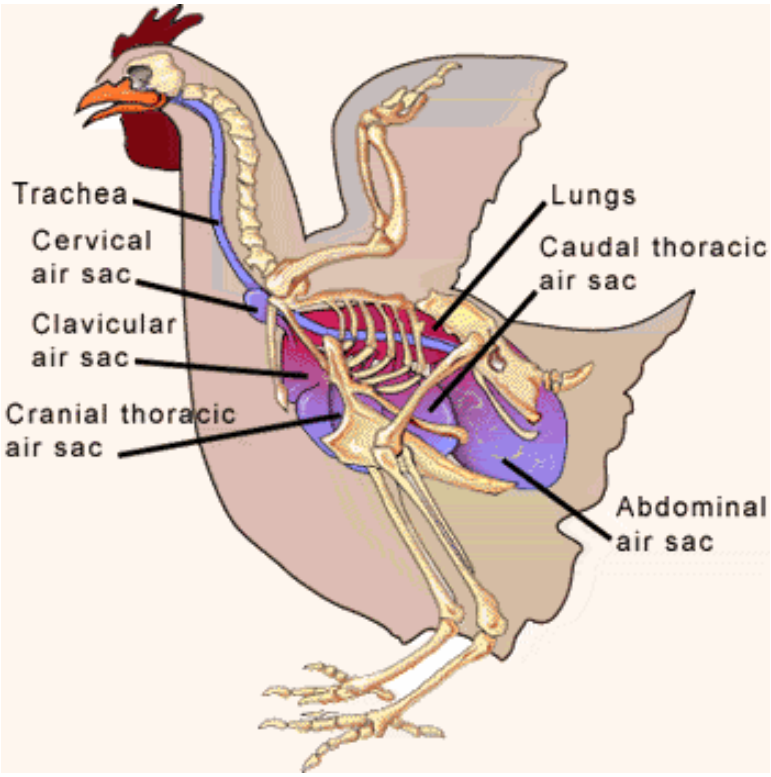
The lungs are not used for respiration until just before the chick hatches. In the meantime we have seen that the chick uses the **allantois** to breathe.

The amount of oxygen supplied through the egg shell is enough until the chick starts the exhausting process of hatching.

During incubation, the water which evaporates from the egg is replaced by air which is stored in the air cell. By the time the chick begins to hatch, the air cell has grown to fill about 25% of the egg.

The chick's first hatching movements are to break the shell membranes covering the air cell and take its first breaths with its lungs. The oxygen stored in the air cell is enough to allow the chick to break through the eggshell.

2. How birds breathe



Respiration in birds is much different than in humans. These differences are adaptations for flight and for singing.

The bird's **lungs** are relatively small in proportion to its body size compared to humans; they are only half the size.

Human lungs are made up of millions of tiny balloons called **alveoli** which expand and contract as we breathe.

A bird's lungs are not elastic, they do not change in size when the bird breathes. Specialized elastic structures called **air sacs** are connected to the lungs and draw air through the lungs. As air passes through the lungs oxygen in the air is exchanged for carbon dioxide in the blood.

Birds have two sets of air sacs: - caudal air sacs
- cranial air sacs

The **caudal air sacs** include the abdominal and the caudal thoracic air sacs.
The **cranial air sacs** include the cervical, clavicular and the cranial thoracic air sacs.
As we know air sacs even extend into the bones. Air sacs inflate or deflate when the size of the bird's chest changes. The bird controls this by moving its muscles. The largest of the air sacs, the abdominal air sac surrounds the abdominal organs and is largely responsible for breathing while the bird is at rest.

As a bird becomes more active, it needs more oxygen. Increased movement forces its chest to expand and compress more which in turn inflates and deflates more of its air sacs. This forces more air through the lungs and makes the bird less dense. When a bird flies all its air sacs are filled including those in its bones and makes it light enough to fly.

A bird can also use its air sacs to sing by forcing air through its vocal organs like a bagpipe. Some birds can sing while they fly because they are able to sing when they breathe in as well as breathe out.

Constant airflow supplies birds with more oxygen than humans. This is necessary to maintain their high metabolic rate and for flying.

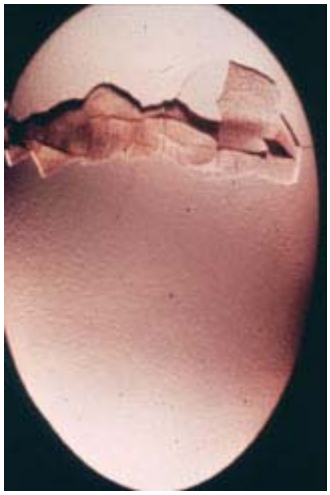
The lungs of the chick begin to form early to be ready when it hatches. Air sacs continue to develop long after the chick has hatched.

Day 21

The neck begins to jerk
The egg tooth pips through the shell
The chick hatches!

Focus on how the chick hatches

The chick usually develops its head towards the large end of the egg. Between day 15-16, the chick orients itself so that its head is near the **air cell**. Soon before the chick is ready to come out of its shell its neck acquires a double bend so that its beak is under its right wing and pointed towards the air cell. About day 19 the chick throws its head forward. Its beak quickly breaks through the **inner shell membrane** into the air cell and the chick's lungs begin to function. On day 20 it will only breathe with its lungs; the allantois no longer works.



Using its **egg tooth** (a tiny sharp horn on the top of its beak) the chick pecks at the shell thousands of times. Finally it pips through the shell and begins to breathe air directly from the outside. After it has made a hole in the shell, the chick stops **piping** for a few hours and rests while its lungs are getting used to the outside atmosphere.

There is a high level of carbon dioxide in the egg compared with the outside environment. This actually causes the neck muscles of the chick to jerk and allow him to peck through the eggshell.

After resting the chick continues to pip by beginning to turn slowly inside the egg. As it turns, usually counter-clockwise, the egg tooth continues to ship away. In about 5 hours, the chick has made about three quarters of a turn inside the egg.

As the chick moves around the shell it begins pushing on the egg cap. Squirming and struggling the chick pushes the cap for about one hour. Finally it breaks free from the shell, still wet and panting.

When the chick is completely out of the shell it lies still.
It is extremely tired. After a rest it begins to rise to its feet and gain coordination.
Within a few days the egg tooth will disappear.

Observing an embryo

1. Use the back of this sheet to write or draw what you think a chicken embryo looks like.
2. After you have observed a developing embryo, draw what you saw in the space below.
3. Compare what you expected to see and what you actually saw. Write a paragraph explaining the difference between what you expected and what you actually experienced.

By day 4 the extraembryonic circulation is fully functional.
Answer the following questions:

What does the yolk sac supply for the embryo?

What does the amion do for the embryo?

What is the function of the allantois.

Glossary

Abdomen - Part of the body between the chest and the legs.

Air cell - The air space between the two shell membranes, usually in the large end of the egg.

Air sacs - Elastic structures connected to the bird lungs that draw air through the lungs. Birds have two sets of air sacs caudal air sacs and cranial air sacs that inflate or deflate according to muscle movement in the bird's chest.

Albumen - The white of an egg, consisting of outer thin, firm, inner thin, and chalaziferous layers.

Allantois - A sac-like external organ located under the egg shell that obtains oxygen, nourishment, and calcium from the egg; and in which is deposited the embryo's waste products.

Alveoli - Millions of tiny balloon-like cells which form the lungs and expand or contract with breathing.

Amnion - A sac filled with fluid that surrounds the embryo and protects it from injury.

Atrium - One of the chambers of the heart which receives blood from the veins. Plural atria.

Avian - Of, relating to, or characteristic to birds.

Avian egg - A bird egg composed of the shell, shell membranes, albumen, and yolk containing the true egg or ovum.

Bantam - A miniature chicken, one third to one fifth the size of a standard chicken.

Blastoderm - A fertilized true egg from which the embryo develops.

Bone marrow - A soft tissue that fills the cavity of most bones and produces blood cells.

Breed - A group of birds that have the same physical features such as body shape or type, color, number of toes, feathered or non-feathered shanks (legs) and carriage or station.

Broody - Characteristic of a hen that wants to sit on eggs and hatch them. Through hormonal changes she has ceased to lay and developed maternal instincts.

Candle - To shine a bright light through the shell to observe development inside the egg.

Carbon dioxide - A heavy colorless gas that is formed in respiration, combustion and decomposition of organic substances.

Cartilage - Elastic tissue which composes most of the skeleton of young vertebrate embryos and is then mostly converted to bone.

Cell - Smallest unit of living matter capable of functioning on its own.

Chalazae - The two whitish cords attached to the yolk of an egg which hold the yolk in the center of the albumen. Singular form chalaza.

Chick tooth - The tiny, horny projection on the top of the chick's beak which it uses to peck holes in the shell when hatching.

Chorion - A membrane surrounding both the yolk sac and the amnion that fuses with the allantois.

Circulatory - Of or relating to the system of blood vessels, blood and heart concerned with the blood circulation.

Class - A group of chicken breeds from the same geographical origin or showing similar characteristics.

Cloaca - The vent or common opening in birds through which the digestive, urinary, and reproductive tracts empty.

Comb - The fleshy, red outgrowth on top of a chicken's head. There are eight types of combs.

Cuticle - A secretion of the uterus consisting mainly of protein that serves to partially seal the pores of the egg shell and acts as a lubricant when the egg is laid.

Down - Soft, fine, hair-like feathers on young birds.

Earlobes - The fleshy patch of bare skin below the ears.

Egg - The microscopic reproductive cell of the female; the true egg or ovum. Also see Avian egg.

Embryo - The early stage in development of the chick within the egg.

Embryology - The study of the formation and development of embryos.

Extraembryonic membranes - Membranes outside the embryo's body that provide respiration, nutrition, excretion, and protection. They include the yolk sac, amnion, chorion and allantois.

Fertile - The capability of an egg to develop into a chick.

Fertilization - The union of a male reproductive cell with a female reproductive cell.

Fetus - The chick during the later development stages in the egg.

Follicle - The sac in which an ovum and its yolk are held until the yolk matures and is released.

Germinal disc - A true egg that has not been fertilized.

Gizzard - An internal organ of birds made of thick muscles which crushes and grinds food by muscular action and with pebbles or grit.

Hatch - To come out of the shell for a chick.

Hemoglobin - An iron containing chemical of the red blood cells that carries oxygen from the lungs to body tissue.

Hock - A joint in the legs of animals.

Humidity - Moisture in the air.

Incubation - The process of applying heat to eggs and causing them to hatch.

Infertile - An egg that is not fertilized and will not hatch.

Infundibulum - The upper, funnel end of the oviduct that picks up the yolk after its release from the ovary and where fertilization takes place.

Isthmus - The section of the oviduct following the magnum; it forms the inner and outer shell membranes of the egg.

Magnum - The section of the oviduct between the infundibulum and isthmus where the thick white of an egg is formed.

Metabolic rate - The rate of the processes by which a substance is handled in the body.

Nutrient - Nourishing substance or ingredient.

Organ - A group or sells and tissues that perform a specialized body function such as a heart.

Ossification - Process by which bones become hardened.

Osteoblasts - Type of bone cell which is responsible for making the structure and laying in the minerals.

Osteoclasts - Type of bone cell which is responsible for shaping the bones as they grow.

Osteocytes - Type of bone cell which is responsible for carrying nutrients to the bones.

Ovary - The female organ that holds the true eggs cells and produces the yolks.

Oviduct - The female bird organ which puts the albumen, shell membranes, and shell around the yolk.

Oviposition - The release of an avian egg from the oviduct.

Ovulation - The release of a true egg or ovum from a follicle in the ovary.

Ovum - The female germ cell or true egg; plural form is ova.

Oxygen - A colorless odorless gas that is found in the air and is essential to life.

Pip - To break through or peck holes in the shell by the chick.

Plasma - The fluid part of the blood.

Pneumatized - Relating to bird bones containing air sacs which are filled by wing movement to make the bird light enough to fly.

Porous - Permeable to fluids due to thousands of pores or minute openings in the eggshell through which gases are exchanged.

Relative humidity - Amount of moisture contained in the air compared with the amount that the air could contain at a particular temperature. It is expressed as a percentage.

Set - To put eggs under a broody hen or in an incubator to hatch them.

Shank - Part of the leg between the knee and ankle or a corresponding part in animals.

Shell membranes - Two thin membranes next to the shell and surrounding the albumen and yolk, known as inner and outer shell membranes. They are one of the egg's main defenses against bacterial invasion.

Sperm - The microscopic reproductive cell of a male; the male germ cell.

Uterus - The section of the oviduct next to the isthmus that secretes a portion of the albumen and all of the shell and shell pigment.

Vagina - The final section of the oviduct connected to the cloaca in which the cuticle or "bloom" on an egg is added and where the eggs are turned so that the long axis is laid first.

Variety - A subdivision of a breed. Different characteristics include feather color, comb type and the presence of a beard.

Ventricle - One of the chambers of the heart which receives blood from the atrium of the same side and pumps it to the arteries.

Wattles - The fleshy, red growths that hang from the side and base of the chicken's beak.

Yolk sac - Membrane that surrounds the yolk and connects it to the embryo's body also called vitelline membrane. The portion of the unused yolk drawn into the chick before hatching.

References

For information on embryological development

Inside an egg — Sylvia A. Johnson, Lerner Natural Science Books, 1987

Window into an egg — Geraldine Lux Flanagan, NY Young Scott Books, 1969

From Egg to Chick — S. F. Ridlen and H. S. Johnson, K. W. Koelkebeck. 1992, Circular LA0950, University of Illinois, Urbana, Illinois.

Avian embryology — 24 x36" color poster showing development over 21 days
Carolina Biological Supply – CD-ROM also available.
Microscope slides of early development (13-96 hours) – Wards
Chicken development museum mount - Wards

For information on embryology projects such as coloring, windowing or preserving embryos

Avian embryo — Publication 1150. Extension service of Mississippi State University
Or visit www.msstate.edu/dept/poultry/avianemb.htm

For activities using computers with access to the internet

EggMath — A collection of web modules (including many interactive applets) covering different topics in mathematics related to eggs for use in K-12 classrooms. Chickscope project at the Beckman Institute
http://chickscope.beckman.uiuc.edu/explore/eggmath/

MRI Database — Searchable database of over 2000 MR images of embryo development. Chickscope project at the Beckman Institute
http://chickscope.beckman.uiuc.edu/explore/database/

Incredible, edible egg — The American Egg Board website contains a wealth of information about egg nutrition, egg sizing and grading, etc. www.aeb.org

Acknowledgements

We wish to thank Cornell Rural School and the Imaging Technology Group - Beckman Institute for Advanced Science & Technology – University of Illinois at Urbana-Champaign for their wonderful graphics. Our warmest thanks also to Purdue Research Foundation for their amazing photographs of developing embryos.

Brinsea Products Inc. – The Incubation Specialists
704 N. Dixie Ave., Titusville, FL 32796, USA.
Tel: (321) 267 7009 Fax: (321) 267 6090
Email: Sales @Brinsea.com www.Brinsea.com