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International Education Series

EDITED BY

WILLIAM T. HARRIS, A. M., LL. D.

VOLUME XLVIII

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BEING PART II OF
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A MANUAL OF INDUCTIVE
ELEMENTARY WORK

BY
EDWARD GARDNER HOWE
AUTHOR OF SYSTEMATIC SCIENCE TEACHING



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A. M. C.

EDITOR'S PREFACE.

IN my preface to the former volume * I have discussed the subject of cultivating observation. It is admitted on all hands that school training should cultivate habits of observation, but when the next question is considered, namely, the best method of accomplishing this, serious difficulties arise. The readiest answer to the question is found in the epigram, "Learn to see by seeing, learn to observe by observing." To the thoughtful person, however, it occurs at once that the acute seeing of the hawk or greyhound does not lead to a scientific knowledge, and that persons with excellent seeing and hearing capacity in general, but without scientific training, are always very poor observers. More than this, an education in science, although it fits a person to observe in the line of his own specialty, does not fit him to observe in the line of another science which

* Systematic Science Teaching, vol. xxvii of the International Education Series.

he has not investigated. On the contrary, the training in one particular line rather tends to dull the general power of observation in other provinces of facts. The archæologist Winckelmann, cited by me in the preface referred to, could recognize a work of art by a small fragment of it, but it does not follow that he could observe a fish's scale and recognize the fish to which it belonged. On the other hand, Agassiz could recognize a fish from one of its scales, but could not, like Winckelmann, recognize a work of art from one of its fragments.

In studying the lessons in botany, which are skillfully arranged by Mr. Howe in this book, the pupil will be greatly helped in his power of observation of the plant world, and, compared with one of his fellows who has not studied botany, he will observe from week to week and year to year, and retain in his memory, thousands of particulars in regard to the plants which he sees in his environment, and which his fellow-pupil would pass entirely unnoticed.

This is equally true as regards the lessons on minerals and rocks, on the stars and the earth, and on the animal kingdom. The power of observation will be sharpened to such a degree that the pupil will become observant in a hundred new ways. Traveling in southern Texas on a midwinter night his attention would be drawn to a bright star near the southern horizon, pretty nearly on the meridian of the constel-

lation Orion. He would be likely to remember that in former studies of the star map his attention had been called to a star of the first magnitude, very familiar to stargazers in the southern hemisphere, and he would inquire eagerly, "Is this not Canopus, once thought to be the nearest of all fixed stars to the earth?" The person who had never made these amateur studies in astronomy would, on a similar journey, glance without interest or special attention at the bright reddish star eight or ten degrees above the southern horizon. Illustrations like these will readily occur to any one who has considered the true method of cultivating observation. It is not perception pure and simple that makes observation, but it is rather what is called *apperception* (the use of the stored-up results of the aggregate perception of the race) that gives one power to see new objects and explain familiar objects.

It is hoped by the publishers that this new volume will meet with the gratifying reception accorded to the former volume.

W. T. HARRIS.

WASHINGTON, D. C., *January 25, 1900.*

AUTHOR'S PREFACE.

SCIENCE TEACHING has made great progress of late years, and the conclusions in the preface to my former volume need no modification here.

Encouraged by the kindly words of the press and of teachers regarding Volume I for the primary grades, the present volume has been prepared to provide a symmetrical graded course in natural science for the higher grades of the grammar school.

It is confidently hoped that my labors may prove an efficient aid and suggestion to teachers and school officers in establishing definite and progressive graded work, and thereby hasten the day when instructors of natural science in our high schools and colleges may be able to base their work upon as substantial a basis of preparation as do those in language and mathematics.

Only as this is done, can the subject become the educational factor which its peculiar relation to the child, its subject-matter, and its methods so aptly fit it to be.

My thanks are due to so many teachers and experts for kindly advice and criticism, that I can only ask each to accept my grateful acknowledgment in proportion to his aid. To Dr. William T. Harris and my publishers I am under especial obligations for their unfailing courtesy and kindness through all the difficulties incident to the editing and printing of a book of this character.

EDWARD G. HOWE.

UNIVERSITY OF ILLINOIS,
URBANA, *January, 1900.*

The Relation of the Several

YEAR OF WORK.	A. THE STARS AND EARTH.	B. MINERALS AND ROCKS.
1st.	The Skies (general). II. Early winter. 10 lessons.	Metals sorted. III. Winter. 12 lessons.
2d.	The Moon. VII. Win- ter. 10 lessons.	Minerals sorted. VIII. Winter. 15 lessons.
3d.	The Earth. XVI. Spring. 20 lessons.	Minerals and Rocks sort- ed. XIV. Winter. 15 lessons. Pebbles. XV. Winter. 30 lessons.
4th.	The Earth (<i>continued</i>). XXII. Late spring. 25 lessons.	How Sharp Stones came to be. XX. Winter. 20 lessons. Plane Form and Color. XXI. Winter. 20 lessons.
5th.	The Solar System. XXIV. Early winter. 25 lessons.	Metals studied. XXV. Winter. 20 lessons. Solid form. XXVI. Win- ter. 20 lessons.
6th.	Gravitation. XXX. Late fall. 20 lessons.	Molecule Lessons. XXXI. Winter. 30 lessons.
7th.	Light, Telescope, Spec- troscope, Laplace. XXXV. Late fall. 30 lessons.	Crystals. XXXVI. Win- ter. 20 lessons. Minerals studied. XXXVII. Winter. 30 lessons.
8th.	The Early History of the Earth. XLII. Win- ter. 25 lessons.	Coins. XLIII. Win- ter. 10 lessons. Earth-making. XLIV. Spring. 40 lessons.
9th.	Other Systems than Ours. XLVII. All through year. 20 lessons.	Rocks. XLVIII. Win- ter. 50 lessons.

Steps to Each Other.

C. PLANTS.

Sorting Seeds and Fruits. I. Autumn. 20 lessons.

Buds. IV. Spring. 15 lessons.

Roots and Stems. VI. Autumn. 10 lessons.

Typical Leaves. X. Early summer. 15 lessons.

Trees. XII. Autumn. 12 lessons.
Woods and Barks. XIII. Winter. 15 lessons.

Flowers. XVII. Late spring. 25 lessons.

Fruits studied. XVIII. Autumn. 25 lessons.

The Life History of One Plant. "Morning-glory Lessons." XXIII. Autumn. 45 lessons.

Relationships of Plants. XXVIII. Autumn. 30 lessons.

(To man, see Step XXXII.)

Winter Quarters of Plants. XXXIV. Autumn. 30 lessons.

Parts and Structure of Fruits. XL. Autumn. 20 lessons.

Corn and Beans. XLI. Autumn. 20 lessons.

Important Families of Plants at Sight. XLV. Spring. 25 lessons.

Important Families. XLVI. Autumn. 25 lessons.

D. ANIMALS.

Eight Home Animals. V. Early summer. 35 lessons.

Twenty-three Familiar Animals of Spring and Moral Lessons connected. IX. Spring. 50 lessons.

Thirty-three Foreign and Less Familiar Animals. XI. Autumn. 50 lessons.

Boy studied. XIX. Early winter. 40 lessons.

Boy Study applied to a Series of Typical Animals. XXVII. Late spring. 50 lessons.

Winter Quarters of Animals. XXIX. Late autumn. 20 lessons.

Man at Home. XXXII. Spring. 40 lessons.

Life Histories of Types. XXXVIII. Late spring. 25 lessons.

Life Histories of Types (*continued*). XXXIX. Time and lessons as required.

Animal Groups. XLIX. Spring. 40 lessons.



SYSTEMATIC SCIENCE TEACHING.

PART II.

STEP XXIV.—THE SOLAR SYSTEM.

So far, the general survey of Step II led to a study of the moon and months (Step VII); that, to the earth's daily motion, day and night, and longitude and time in Step XVI. Continuing, came in Step XXII the yearly motion of the earth and inclination of its axis to the ecliptic, resulting in the year, with its varying day and night, heat and cold, causing the four seasons, and determining the position of the five parallels of latitude to which all others must agree.

These steps follow each other in easy, logical order; and now we shall proceed to consider the earth as a member of a family called **The Solar System**. How truly its parentage is shown by the name will appear in Step XXXIV. Another purpose in this star work, especially on the constellations, is to **improve the eyesight** by *long-range* vision. So much of the school work and city seeing is at short range as to prove a serious injury to the eyes, and it is believed by good authorities that the cultivation of habits of long-range sight will do much to counteract this.

The Time needed will be about twenty-five lessons of fifteen to twenty minutes each, but much of this will be reading. I have arranged the step to come in November, when the constellations can be seen.

Material.—Some good drawing paper, pencil-pointed compasses, and water colors (see XXX) will be needed, besides the globes. Get for the use of the class as many telescopes, "spy," field, or opera glasses, as can be found. The very poorest will be helpful.

Preparation of the Teacher.—But little need be added to the suggestions of Step XVI. Review previous steps, read in books about the solar system, the remaining six zodiacal constellations, and go through this step carefully before beginning with the class.

THE LESSONS.

Question briefly on the past steps to make the connection, as follows:

What is the shape of the sun? The moon?

Why does the moon seem to change its shape?

Is the light of the moon its own, or borrowed?

Which way does the moon travel around the earth?

Why is the month about thirty days long?

Name the months in order.

What do some of these names mean?

What proofs have we that the earth is spherical?

Tell of an experiment which shows its revolution on its axis.

Why is our day twenty-four hours long?

What were some of the ancient ways of telling time?

Give the names of the days of the week.

Why do the sun and moon seem to rise in the east?

How do we know the earth is traveling around the sun?

Where did we get the year of $365\frac{1}{4}$ days?

What is an eclipse? How caused?

What causes the days and nights to vary in length?

How much is the axis inclined?

What parallels are $23\frac{1}{2}^\circ$ from the poles? From the equator?

Name the four seasons and their meaning.

Why is winter cold and summer warm ?

Why is the sun said to "pass through" such and such constellations ?

Does he really do so ?

Describe our illustration with pictures on the wall.

What is the belt through which the sun seems to pass called ?

Name its twelve constellations, beginning with April's.

The north pole points to what star ? (Pole star.)

To what constellation do the "pointers" belong ?
(Great Bear.)

What bright star do those of the Bear's tail lead to ?
(Arcturus.)

What semicircle of stars near Arcturus ?

What mighty hero is next the Crown ?

What skin is Hercules supposed to wear ?

Where is the Lion, and how known ?

Where is the Hydra ?

If Draco guards the Golden Apples, where must they lie ? (Near the Little Bear.)

What group east of the Lion in May ?

What does the Virgin hold in her hands ?

East of the Scales lies what group ?

Constellation east of Scorpio in July ?

What does Sagittarius represent ?

How can Capricornus be distinguished, and where ?

Other Planets.

Get almanacs, and find which are to be seen, and when. The planets Venus and Jupiter are most easily seen, and they should be watched to see that their position among the constellations *changes*. Mars and Saturn are conspicuous, but not quite so much so as Jupiter.

Let the class make diagrams in their notebooks of the positions once a week till the motion is easily noted.

What does the word "planet" mean? (Wanderer.)
Why?

Which way do they "wander"?

This might be found by *observing* for some time, especially if opera glasses were used, but I would advise showing the class such pictures (those on p. 136, Lockyer, or pp. 186 and 192, Burritt) as will illustrate the *phases* of some of the planets.

These will at once suggest the moon and the question whether the planets revolve about the *earth*.

Now take the lamp and little globe and follow the plan in Lockyer's *Astronomy Primer*, pp. 56-59, and I think any class can be led to see that no planet revolving *between* us and the sun can be seen at *midnight* (as we can the moon), and must be either a "morning" or "evening star," having phases like the moon.

Also, that any planet *farther* from the sun than we, and so nearest to us when opposite the sun, will *always* show a bright face to us. No "moon" could ever appear in either of these ways, and as some "wanderers" show decided phases and are only seen for two or three hours at either morning or evening, and *never* at midnight, we know there are "interior" planets.

As other "wanderers" are brightest when seen opposite the sun, and never distinctly show the "horns" of a new or old moon, we know there are "exterior" planets.

How many of each kind are there?

Astronomers (those men and women who study these things and think carefully about them) have found out much, and we will go to their books to see.

How many do they say? ("Two interior, the earth, and five large exterior planets—*eight* in all.")

Relative Size of the Planets.

How large are they, compared with the sun?

All have been carefully measured, and let us first try to get an idea of how large the sun is.

Class draw Diagram 1.

Sun's diameter = 850,000 miles. Represent by a circle with 43 mm. radius.

Moon's orbit = 480,000 miles. Represent by a circle with 24 mm. radius.

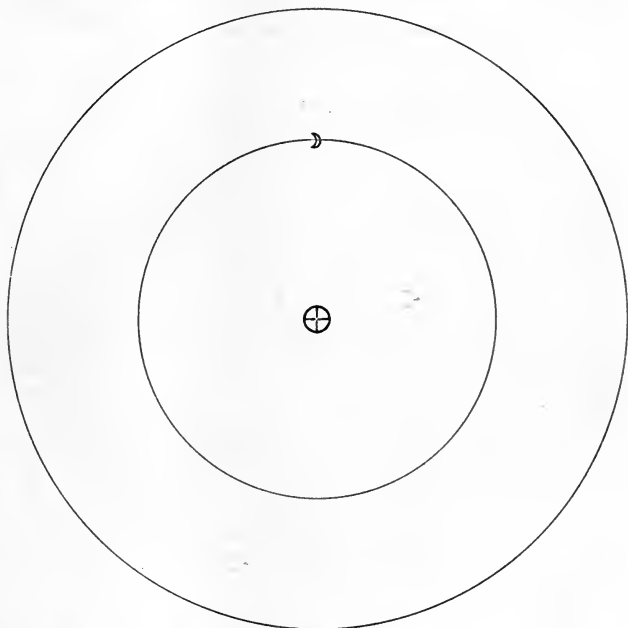


FIG. 1.—SIZE OF THE SUN.

Sun 850,000 miles = 84 mm. = 42 mm. radius; Moon's orbit 480,000 miles = 48 mm. = 24 mm. radius. If the sun were hollow and the \oplus at the center, there would be room for the \ominus 's orbit and 200,000 miles outside.

Place the earth (\oplus) at the center, and the moon (\ominus) on her orbit.

Color the sun (outside moon's orbit) a bright yellow or orange.

Color the moon's orbit with a wash of blue.

Write neatly below what the card represents.

Diagram 2.—Describe circle with 50 mm. radius. Draw a very light line across (diameter), and mark it

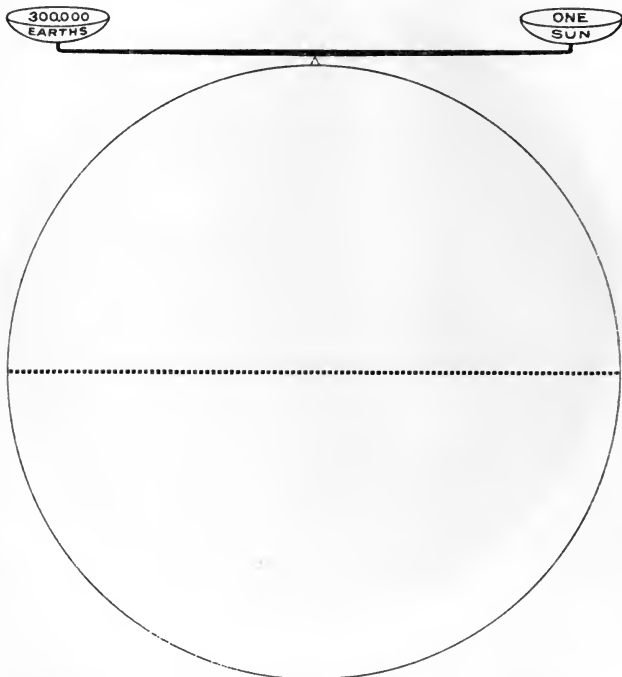


FIG. 2.—SIZE OF THE SUN.

If a hole the size of the \oplus were bored through the \odot and \oplus 's dropped in, it would take 100 \oplus 's to fill the hole. If hollow, the \odot would hold over 1,000,000 \oplus 's.

into 100 spaces with a mm. scale. Make a little circle on each space to represent the earth, 100 of which equal in diameter the large circle. On the top place a "knife

edge" (Δ) and evenly on it a 10-cm. line. Draw pans at either end, and in one write "sun" and in the other "300,000 earths." Color to suit taste, and write what it represents.

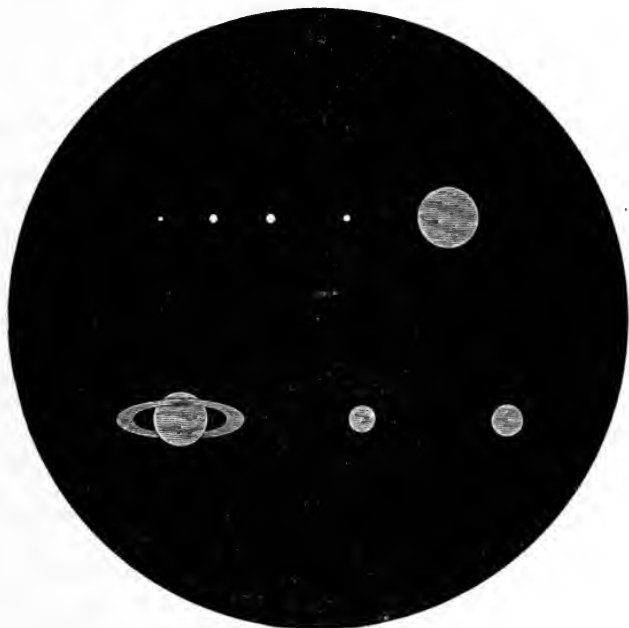


FIG. 3.—RELATIVE SIZE OF SUN AND PLANETS.

\odot , 84 mm.; ♁ , $\frac{1}{3}$ mm.; ♀ , 1 mm.; ♁ , 1 mm.; ♂ , $\frac{1}{2}$ mm.; ♃ , 8 mm.; ♄ , 7 mm., ring 17 mm.; ♃ , $3\frac{1}{2}$ mm.; ♆ , 4 mm.

Diagram 3.—With 42 mm. radius, draw a circle to represent the sun. On two faint horizontal lines, extending, the one above and the other below the center, represent the eight planets as follows:

Mercury (♁) by a dot. Color, orange.

Venus (♀) by a dot 1 mm. in diameter. Color, green.

Earth (\oplus) by a dot 1 mm. in diameter. Color, green.

Mars ($\♂$) by a dot $\frac{1}{2}$ mm. in diameter. Color, red.

Jupiter ($\♃$) by a dot 8 mm. in diameter. Color, pale red.

Saturn ($\♄$) by a dot 7 and ring 17 mm. in diameter. Color, blue and ring white.

Uranus ($\♅$) by a dot $3\frac{1}{2}$ mm. in diameter. Color, pale blue.

Neptune ($\♆$) by a dot 4 mm. in diameter. Color, pale blue.

Having drawn (in light lines) the planets, color the *whole* the bright yellow or orange which we have adopted to represent the light and heat of the sun, and when *perfectly* dry, color the planets as indicated above.

Reasons for the colors given are these: Mercury is difficult to see, and hot (see Lockyer, p. 259); Venus is much like the earth, and the earth is clad in *green*; Mars is the "fiery red" planet; Jupiter, pale red, because there are reasons for thinking this huge planet (fourteen hundred times the size of the earth) is still quite *hot*. A *cold blue* has seemed most appropriate for planets distant in space.

Pins and balls will still further illustrate this matter of relative size and distance.

"Mourning pins" (assorted), large-headed shawl pins or hairpins, marbles, and rubber or wooden balls can be called into service to make up a set. (See Lockyer's suggestion, p. 76.)

These measurements are, of course, only approximations, but as near as need be required.

Measure the globe you may have, and then find pins and balls to correspond. I would let each pupil (who wishes) make up a set to keep, sticking the pins in a card and marking over each one what it represents and the *size* of globe they go with. The class will now have an idea of the relative *size*.

DIAMETER OF PIN, ETC., TO REPRESENT	SUN REPRESENTED BY A GLOBE OF			Distances (1 mm. = 18,000,000 miles).
	8 inches (200 mm.).	12 inches (300 mm.).	16 inches (400 mm.).	
Mercury (☿).....	$\frac{3}{4}$ mm.	1 + mm.	$1\frac{1}{2}$ mm.	2 mm.
Venus (♀).....	2 — “	$2\frac{1}{2}$ “	$3\frac{1}{2}$ “	4 “
Earth (⊕).....	2 “	3 “	4 “	5 “
Mars (♂).....	1 “	$1\frac{1}{2}$ “	2 “	8 “
Jupiter (♃).....	20 “	30 “	40 “	26 “
Saturn (♄).....	17 and ring 40 mm.	25 and ring 60 mm.	34 and 80 mm.	48 “
Uranus (♅).....	7 — mm.	11 mm.	15 mm.	97 “
Neptune (♆).....	8 — “	12 “	16 “	152 “

Diagram 4. Relative Distances of the Planets.—Get pieces of drawing paper (manilla will do) 400 mm. square. Find the center, and place a gilt star or draw a sun. Now describe circles around this central sun at the successive distances from its *outer* limit that are given (for convenience) in the last column of the above table.

On each orbit now place the proper *planet*—the same size as given in the table—and *color* them as for Diagram 3. We now have a very interesting chart representing the *relative distances* (see Lockyer, p. 75). Say nothing of the moons at this point, but save these charts to put them in later.

Set Pins.—Agree on some scale (1 foot to the mm. I use) and let the class lay off these distances on a level fence or sidewalk, and then stick the pins (through paper labels), and place the balls in the proper places. This is an exceedingly interesting and instructive exercise, and the respect of the pupils for the size of our planet “family” and the enormous distances between them should have made a considerable and healthy growth.

This can be deepened and broadened by turning to page 296 of Lockyer and talking of the *year* each one has, varying from 87 *days* for Mercury to 165 *years* (of ours) for one of Neptune’s.

Direction of Motion.—Arrows should be placed by each planet on Diagram 4 to show this. All point opposite to the motion of the hands of a watch.

Plane of the Ecliptic.—Refer again to this, illustrating it in some such way as before given (see Step XXII), or by a sheet of cardboard with the circles of Diagram 4 on it, and holes the proper size cut to lay the planets in, and then speak of the other large planets (Lockyer, p. 74). Mercury and Venus are the only ones which differ much from our earth's plane.

Moons of the other planets.

Let the class take Diagram 4 and add the proper number of satellites to each (Lockyer, p. 75).

The class may be interested in referring to Lockyer (p. 297) and noticing the size, distance, and period of revolution of these. When the idea of such revolution about the primary is before the class, lead them to speak of Jupiter's moons in particular, and of the *eclipses* and *disappearances* which must occur as the moons revolve about the planet (Lockyer, p. 145, and Burritt, p. 236, etc.).

Speed of Light.—By circles on the board, represent the sun, earth, and Jupiter, and tell how Roemer's observations on these moons when Jupiter was nearest to, and farthest from, the earth led to the discovery of the *speed of light*.

Would go over Roemer's calculations with the class (Burritt, p. 239).

Meaning of Names and Signs (Lockyer, p. 71).

Comets.—Briefly refer to these strange members of our "family." Show pictures and read about them.

Constellations.—Continue those of the zodiac. Begin in September or October to observe. (See Astronomy with an Opera Glass; Serviss, Chapters III and IV.)

Review Capricornus and such others as may be visible of those before learned. Then pass east to

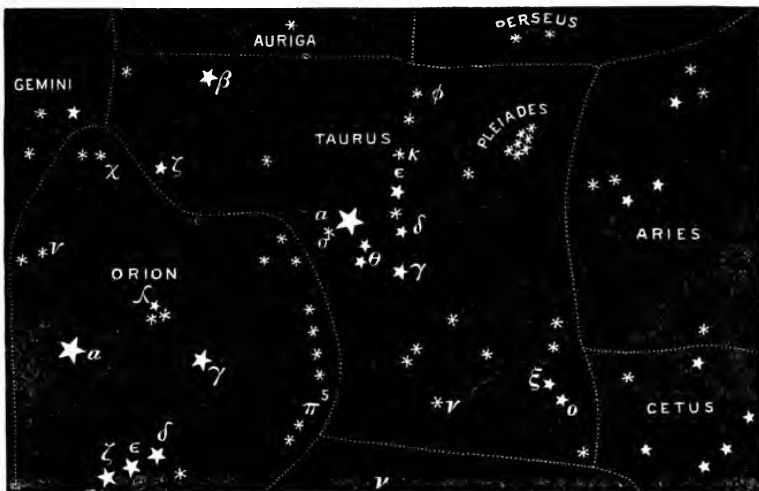
Aquarius, who is represented as holding an urn from which flows a river of water down to where the southern Fish swims in it. Connected with this constellation are the stories of Ganymede (see Burritt, p. 132), and the overflow of the Nile.

Pisces.—When Aquarius is in the south, this constellation will be in the southeast. The stars are small, and but little of interest is connected with the group except as being the first of the zodiac, and that in which the sun seems to enter at the beginning of *spring*.

Aries lies east of the Fishes, and is most easily found by the two stars in the head.

This is the ram which bore the famous fleece of gold. (Bulfinch, p. 158; Burritt, p. 30; Greek Heroes, The Argonauts, and Hawthorne's Golden Fleece.)

Taurus.—The Bull. As the Ram gets into the south, this beautiful group will appear directly east. Not only



are the stars in two beautiful clusters (Pleiades and Hyades), but much interesting history and fable cluster about them. (See Burritt, p. 41 ; Bulfinch's Europa, Pleiades, Hyades ; and Hawthorne's Dragon's Teeth, in Tanglewood Tales.) The mythology might easily extend to the Argonauts, etc., but I have thought best to leave everything but the groups of the zodiac here.

As Taurus passes to the west, in the east and south-east will arise **Gemini**, or the Twins. While the Bull is on the *west* of the milky way the Twins are on the opposite side, and the group is peculiar for the *rows* or lines of stars it contains. The two brightest ones are in the heads of the Twins ; from these, rows extend to a foot of each, and intermediate stars make three cross-bands in the *heads, knees, and feet*. These brothers had a remarkable history. (See Burritt, p. 55 ; Bulfinch : Castor, etc.)

Cancer (the Crab) lies next east ; not a brilliant group, nor having much that is interesting to young classes about it. (See Burritt, p. 65.)

Review.—Question on what has been told and learned. Hang the twelve constellations (diagrams) around the room, and repeat the experiment with lamp and small globe (Primer, p. 19, etc.). This will have an added interest now.

Next step in this study, XXX.

STEP XXV.—METALS STUDIED.

The object of these lessons is :

1. A more intimate acquaintance with metals than Step III gave.
2. Advance in experimenting.
3. To prepare for work in minerals.

Time.—About twenty lessons of fifteen to twenty minutes each.

Material.—In addition to that of Step III, get the following :

Magnesium ribbon,	}	Get from dealer in chemicals.
Metallic antimony,		
Metallic bismuth,		
Platinum wire,		
Aluminium wire,		
Mercury,		
Metallic potassium,		
Metallic sodium.		

Tin plate,	}	Get at tinsmith's.
Galvanized iron.		

Magnets of Step III.

The hard-tile streak plates of Step VIII.

Alcohol lamps of some kind (a piece of large glass tubing through the cork of an ink bottle does nicely).

Pincers to hold the pieces while heating.

Cut the magnesium into pieces $1\frac{1}{2}$ inch long.

Cut the platinum and aluminium wire into bits 1 inch long.

Break carefully the antimony and bismuth into pieces the size of a white bean or pea.

METAL LESSONS.

Record of observations by.....

METAL.	WEIGHT.	Is it magnetic?	Bent to right and left— —brittle. Springs back— elastic. Stays bent—flexible.	Pound gently. Is malleable or brittle.	COLORS		To scratch is hard. Medium. Soft.	Heat in flame. Burns, melts, or rusts.	Left in water! Rusts, etc.
					Of streak mark on tile.	Of fresh surface.			
Copper.....	M.	No.	F.	M.	Copper red.	Copper red.	S.	Slight.	
Gold.....	H.	No.	F.	V. M.	Gold yellow.	Gold yellow.	S.	Cleaner & brighter.	
Brass.....	M.	No.	E.	M.	Brass yellow.	Brass yellow.	M.	Slight.	
Bronze.....	M.	No.	E.	M.	Bronze.	Bronze.	M.	None.	
Lead.....	H.	No.	F.	M.	Bluish gray.	Lead gray.	S.	Tarnish.	
Zinc.....	M.	No.	F.	M.	Gray.	Bluish white.	S.	Melts.	
Magnesium.....	L.	No.	E.	M.	Gray.	Grayish white.	S.	Gray rust.	
Type metal.....	H.	No.	B.	V. B.	Gray.	Lead gray.	S.	Melts.	
Antimony.....	M.	No.	V. B.	V. B.	Dark gray.	Bluish white.	M.	Smokes and melts.	
Bismuth.....	H.	No.	V. B.	V. B.	Reddish gray	Reddish white.	S.	None.	
Wrought iron.....	M.	Yes.	F.	M.	Gray.	Grayish white.	M.	Red rust.	
Cast iron.....	M.	Yes.	B.	B.	None.	Iron black.	H.	Black.	
Steel (tool).....	M.	Yes.	E. to B.	M.	Gray.	Steel gray.	H.	Softer.	
Nickel.....	M.	Yes.	F.	M.	Dark gray.	Grayish white.	M.	None.	
Tin plate.....	M.	Yes.	F.	M.	Dark gray.	Tin white.	.....	Tin melts off.
Tin foil.....	M.	No.	F.	M.	Dark gray.	Tin white.	S.	Burns.	
Silver.....	H.	No.	F.	M.	Silver white.	Silver white.	S.	Cleaner & brighter.	
Platinum.....	H.	No.	E. to F.	V. M.	None.	Tin white.	M.	Glows.	
Aluminium.....	L.	No.	F.	M.	Gray.	Grayish white.	S.	Cleaner.	
Mercury.....	H.	No.	Liquid.	.....	.....	Silver white.	Liquid.	None.
Potassium.....	L. Floats.	.....	.....	.....	.....	Reddish white.	V. S.	Takes fire!
Sodium.....	L. Floats.	.....	.....	.....	.....	Silver white.	V. S.	Violet flame. Takes fire! Yellow flame

Put drops of mercury the size of a pea in glass vials, enough to go round, and cork them.

The sodium and potassium should not be given to the class, only passed around at the last for examination, and then pieces placed on water by the teacher to show how they *float* and *take fire*.

See that all the metals have somewhere a clean, bright surface.

Expense.—About five dollars, in addition to materials before suggested.

Preparation of Teacher.—With the specimens before you in twenty-one boxes, arranged in a tray, compare your results with those of the table on page 14.

I find much disagreement in books regarding color and hardness. A careful study of my sets of specimens gives the following results. Other material, especially of alloys, will doubtless differ.

The order in which I have arranged the metals has aimed to group those resembling one another, so as to aid in comparison.

The reasons for the order of work are as follows:

1. **Weight**, determined before the material is cut or broken up.*

* This has always been a trouble to me, from the difficulty of getting *equal*-sized pieces of the different metals large enough for the hand to judge of the relative weights.

I have tried two ways:

A. I got coins of gold, silver, bronze, copper, and nickel of nearly the same size, and pieces of the other metals (last two always excepted), finding the bulk of each by means of a graduated cylinder holding some water, or, better, with a specific-gravity balance. Those whose specific gravity was under 5, I called *light*; under 9, *medium*; and over 9, *heavy*.

B. I kept my metals in medium-sized glass vials, having these all equally full, and passing them around the class before giving out the specimens. Gold, silver, and platinum were here

2. **Magnetic**, before a magnet has touched them.
3. **Bend.** } These aid each other, and the fragments
4. **Pound.** } are needed later.
5. **Streak**, gives a fresh surface for 6.
6. **Color.**
7. **Hardness**, partly shown by the streak plate.
8. **Heat.**—The fresh surfaces (made by pounding) will enable change of color through heat to be seen.
9. **Water** is apt to change the color, and so must be used last.

If the pieces touch or are near each other in the water, the rust from the iron is apt to get on the others; and as it injures so many of the specimens, I would advise separate dishes or shells.

THE LESSONS.

1. Let some pupil **draw** a plan of the **table** (page 14) on the board, the names of the metals at the left and headings of columns at the top, and each pupil draw one to a scale on large paper.

2. **Give** out the **boxes** and empty trays, and direct the pupils while they make neat labels for each box about 4 cm. square.

3. Let the class determine the **relative weights** in such way as may seem best, and each record in his table.

4. **Give** out the **specimens**, as in *C*, Step XIV, being sure that the metals and labels agree.

5. Determine the **magnetism** of all, and record. Now give a pinch of fine iron filings to each. Stroke the un-

in the shape of coin or utensils, as it cost too much to cut them up. But the vials *broke* too easily.

My *wish* has always been to take coin as far as possible, and then have round pieces of the cheaper metals punched the same size and thickness; and if there were a demand for such pieces, they could be had cheaply.

marked end of the magnet with the piece of wrought iron ten times, and then see how many of the filings it will pick up. (A few.)

Do the same with cast iron. (Fewer.)

Same with steel. (Many.)

Same with nickel. (A few.)

Same with tin plate. (Few.)

Lay down the magnet, and try the metals again after the little rest, and decide which **keeps** its magnetism best after rubbing on a magnet. (Steel.)

Let each stroke the **unmarked** end of his magnet with a knife blade or large needle, in each case having the point the last to leave the magnet at each stroke. These can be suspended at home by fine thread (away from iron). Which way do they point? (North.)

Why is tin "plate" magnetic and tin not? (It is iron or steel coated with tin.)

6. **Bend**, and record.

7. **Pound**. This may best be done at close of school. Use "tack" hammers and any piece of iron weighing half a kilogramme or so. Insist that it be held on the lap or knee (to deaden the noise).

8. Give **streak** tiles and record streaks. (It is a good plan to make the streaks in a neat and orderly row across the tile from left to right. To see them all at once is instructive.)

9. Record **color** from fresh surface only. This point is *very* important.

10. **Hardness**.—Take a bit of window glass first. Any that scratch it in the least are "hard." To test the others, take a piece of copper with a sharp corner. Those it will not scratch are "medium." Itself and all it scratches are called "soft."

This "scale of hardness" agrees with the tests of minerals both in Step VIII and Step XXXVII.

11. **Heat.**—Give three-centimetre bits of candle (Christmas tapers will do). Light, and have a talk about the structure of a flame. Place the illustrations from some chemistry on the blackboard in colors.

Note the solid candle ;

the cup of melted wax or tallow ;

the wick, unburnt in the center of the flame ;

the blue base of the flame ;

the dark center, extending a little above the wick ;

the luminous cone, continually disappearing in the air above.

Lead the class to see that everything must be **vaporized** before it burns with a **flame**, by talking of the tongues of flame shooting up from soft-coal fires, and of the jets which shoot and hiss from wood or dart up the chimney.

In the kerosene lamp the liquid oil climbs up the wick and is vaporized by the heat at the top. In the candle, how is it ?

That the center of the candle flame is comparatively cool gas, may be shown by holding a splinter of wood across the flame a few seconds and quickly removing. It will have an unburnt space between two burnt ones.

A sheet of white paper pressed down on the flame and removed before it can take fire shows a ring of charred paper.

Now, by holding a bit of fine wire in the flame, decide which part is hottest. (Tip of inner cone.)

NOTE.—Whether the teacher will explain this depends on the class. Unless he can express himself in terms of the child's experience, he must *not attempt it* ; the observation is enough for the present.

Where, then, shall we hold our metals to try the effect of heat on them ?

Try each metal in as nearly the same way as possible, and record. Let the time be one minute, unless melting or burning takes place sooner.

12. Place twenty-two small dishes in some safe but easily accessible place. Let different pupils bring pieces of metal so that twenty dishes will each have two bits of the twenty different metals in them. Pour on **water**, and leave twenty-four to forty-eight hours.

The class observe the results and record.

Dry and return such of the metals as are uninjured.

Talk of the ways in which this varying behavior affects us—pipes, jewelry, cooking utensils, etc.

13. Here are two metals I did not dare give you. They must be kept in kerosene. See! I can **easily cut** this **sodium** with a knife. Record its hardness. This **potassium** cuts just as easily. Samuel may carry the piece of potassium around for all to look at, and Annie the sodium. No one must **touch** the pieces. Why? Record anything you can about them.

Now observe as I drop the **potassium** on water. (**Floats and takes fire.**) I will try another piece for you to note the *color* of the flame. (Violet.) Now see the sodium. (Floats and rushes about, a silvery globule, till all gone.)

I will try another piece on warm water. (Burns with a yellow flame.)

Why did I ask you not to touch these metals? (Burn fingers.)

Now record, and the lesson is done.

Review.

14. John, name those metals that are heavy.

Mary, those that are light.

Samuel, how many are medium?

Alice, name them.

Do all metals sink in water? Which do not?

Which are magnetic?

- Which one keeps its magnetism ?
Is it magnetized now ?
How could you make a knife point north ?
Name those that are brittle.
Those that are elastic.
What do we call the others ?
What is a "malleable" metal ?
Name those which are.
Name the brittle ones.
What do you understand by "streak" ?
Name those giving metallic streaks.
Those giving no streaks.
Why did they not mark the tile ?
Do any give unmetallic streaks ?
Name the reddest metal.
The yellowest.
The whitest.
The bluest.
How does "brass" differ from "gold" yellow ?
Describe a "bronze" color.
How does "iron black" differ from steel gray ?
Would you accept a dollar made of **tin** ?
How does "tin white" differ from "silver white" ? *
How would you find which metals are hard ?
Name them.
What test for those soft ?
Name the "medium" ones.
Draw a diagram of a candle flame on the board.
Who can tell me how a candle burns ?
Could there be **flame** without **gas** ?
Name as many flames as you can.
What is the dark center ?

* (NOTE TO TEACHER.—The pupil should learn to observe the streaks carefully, for on clear conceptions of metallic colors much depends in the future work.)



How proved cool ?

Where would you hold something to heat ?

Name those metals which **burned**.

Those which **melted**.

Those which changed color.

Which became cleaner and brighter ?

Which metals rusted ?

Have you seen any at home which rusted ?

Will water put out all flames ?

How can we prevent rusting ? (Keep dry by oil, paint, etc.)

After a rapid and exhaustive review in this manner, proceed to test the pupils.

15. **Sort**.—Each empty out his labels and metals in a pile, and then, taking the first label he picks up, find the specimen which belongs with it, and return to a tray. Then take another label and its metal, and so on till done.

Now all are done. Change boxes, and if you find an error, raise your hand. When corrected, return boxes.

16. Each put his metals in a **mixed pile**, and, having changed boxes, sort a set you had not before seen. Bring to me when done. (Teacher keeps them when correct.)

17. **Putting away**.—Clean, dry, and wrap up as directed in Step III, and put away in boxes.

18. **Review from Memory**.—There is no more effective way (for me) of review than the following. It keeps the close attention of all, stimulates thought and memory, pleases the bright, and teaches the dull. "Written reviews" can not compare with its results as regards clear and helpful knowledge of the subject, and I prefer to defer "compositions" to some other time. Of course, the **language** should, as always, be terse and correct.

No child must *repeat* what has been told.

Who will tell me something about metals ?

Some one else tell another thing.

Another.

What more ?

No repeating ; that has been told.

What more ?

In this way the subject can be exhausted, and many interesting things brought out of which the teacher would not think. Some of these will prove errors or misconceptions, and can be set right, while bright and original ideas can be warmly recommended.

This will close an interesting and instructive set of lessons.

Next step, XXVI—Solid Form.

STEP XXVI.—SOLID FORM.

Object.—1. To continue the work begun in Step XXI (Plane Form and Color).

2. To familiarize with some fundamental solids in preparation for the study of crystals, minerals, and other work.

Time.—In late spring, and at such time of the session as the pupils need a rest from study. About twenty lessons of thirty minutes each. As in work on Form, it is best to have fewer lessons and have them longer.

Material.—For a class of thirty there will be needed thirty clay boards, or twelve-inch square pieces of smooth thin board, *well oiled* on both sides to prevent warping, fifty pounds of prepared clay, such as is used in kindergartens, although I do not see why good brick clay would not do as well. Should be in an earthen crock, so as to keep in good working condition.

Preparations of Teacher will consist mainly in taking some clay and mastering the various pieces of work before giving it to the class. There are books on clay work which would doubtless be helpful, but a study of the six systems of crystals in Dana's Mineralogy will suggest what is *needed*, and from those it can be decided which to attempt to make. For those who would suggest *cutting out* crystal forms from potatoes, paraffin, soap, etc., I will say that it *never worked* in the classes of comparatively young pupils I have had. Clay is very tractable material, and a little practice gives beautiful work.

THE LESSONS.

1. Give boards and nearly equal lumps of clay (size of walnut). Roll in the palms till a **sphere** results.

Children's hands are so hot and dry that if success does not soon come the clay becomes dry and *cracks*. Change such lumps for fresh clay. When one ball is made let the pupil work at another, as "practice makes perfect." Have a little plaque made to place the best ball upon, and show how, by moistening, to stick the two together. On the plaque let the owner's name be scratched, and set all in one of the trays used for sorting and put away to dry. It is well for each child to have a cigar or candy box for his work.

2. **Oblate Spheroid**.—Give boards and clay as before.

First, make a sphere.

Second, flatten it a little by unequal rolling. No plaque needed.

3. **Cube**.—First, make a sphere.

Second, by constantly turning and gently dropping the sphere on the board an equal flattening on the six sides will take place. Work at it till eight sharp and square corners replace the rounded surfaces of the ball. Keep trying till it is done well.

4. **Cone**.—First, make an ovoid (egg-shaped).

Second, flatten the base and roll alternately till a cone results.

5. **Square Pyramid**.—First, make another cone.

Second, by carefully dropping on opposite sides in succession change the cone into the pyramid. Of course the bottom must be kept flat, and should be *square*.

6. **Triangular Pyramid**.—First, make a cone.

Second, by flattening the sides in three directions get the triangular pyramid. The bottom should be an equilateral triangle. The idea of threes may be a little difficult, and need illustration.

7. **Octahedron.**—First, make a sphere.

Second, by careful dropping on successive sides change the sphere into a solid with eight triangular faces. These triangles should be approximately equilateral, and some patience be needed to succeed. If the sides should prove *isosceles*, save it to illustrate the dimetric (two-measure) system of crystals.

8. **Cylinder.**—First, make a sphere.

Second, by gently flattening the two poles and rolling down the equator, bring it to a cylinder with two flat and circular bases.

9. **Square Prism.**—First, make a cylinder.

Second, by alternate and gentle flattening change the curved surface into *four equal rectangles* and the circular bases into *squares*. The eight corners should be "square" and sharp.

10. **Rhombic Prism.**—First, make a cylinder.

Second, change this into a prism whose sides shall be rectangles like the square prism, but whose bases are *rhombs*. The sides of the rhombs should be nearly *equal*.

11. **Triangular Prism.**—First, make a cylinder.

Second, working on the principle of threes, change it into a triangular prism, whose sides must be *rectangles* and bases equilateral triangles.

12. **Hexagonal Prism.**—First, make a triangular prism.

Second, flatten the edges until you have six rectangular sides and six-sided ends. This prism can be made directly from the cylinder, but it requires a good deal of judgment to get the six sides equal or very nearly so.

13. **Rectangular Prism.**—First, make a cylinder.

Second, by unequal flattening to adjacent sides change the surface to rectangles, but only those *opposite* shall be equal, and the bases shall be *rectangles*. A brick is a good model.

So far all angles between the bases and sides (except the pyramids) have been *right* angles, and all—even the pyramids—have stood *erect* on their base. All such solids, prisms, and pyramids are called “*right*,” because the line from the center of the top to the center of the base (vertical axis) is at *right* angles with the base.

14. **Oblique Prism.**—First, make a cylinder.

Second, make a prism just like the rectangular prism, except that two of the opposite sides are rectangles and two are *rhomboids*, like those of a box crushed over to one side. The bases will still be rectangles. Are the angles all *right* angles? (Some *obtuse*.) Can you make an oblique prism on a *square* base?

15. **Rhombohedron.**—First, make a cube.

Second, by careful dropping change the square faces of the cube into *rhombs*. Can you find any right angles to the faces? To the edges? Are the corners “square corners”?

16. **Original Designing.**—The rhombohedron ends the work I have given. If you can arrange for the class to do some original work in clay, it will be a good thing, but do not take school time for it. If, as in Plane Form, the chance to work with clay in original designs be contingent on and follow the performance of *excellent* work in the ordinary school studies, a mild stimulus, in no wise hurtful, will be supplied to secure steady and vigorous work on the studies for the sake of the time to be used at clay. But insist that nothing *less* than *excellent work* shall gain the privilege.

17. **Name Solids.**—Let each pupil have his fifteen solids before him, and they will now be hard and dry enough to write on each its name. Put these in a large printing hand on the board, and be sure each child gets the right name and solid together.

18. **Study of Solids.**—Let each child make from cardboard (tin or brass would be better, and cost but little) a copy of this device for measuring angles. Now let

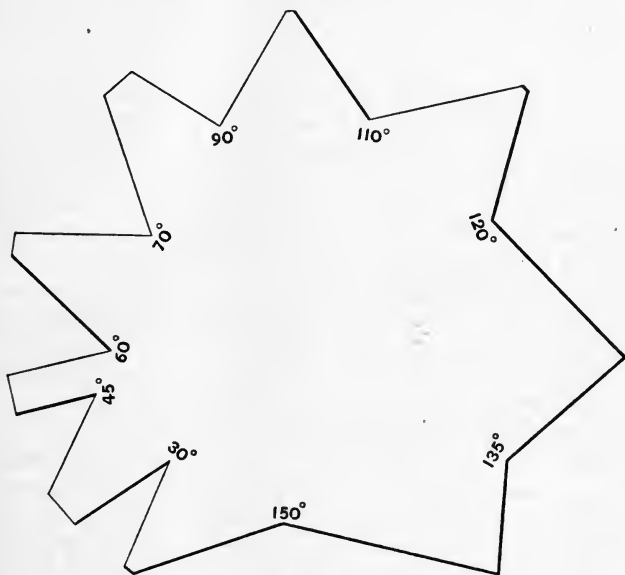


















FIG. 5.

each have his complete set of claywork in a tray, and it will be a great help if the wooden models of crystals suggested in Step XXXVI be also given, as the angles of the claywork will not be very constant or exact. Now draw the lines of the following table on the board and let the class copy, and, with your help, study the solids and fill out.

19. After this measuring of angles, counting and comparing of sides and edges, there only remains the

SOLID	PLANE ANGLES OF		SOLID ANGLES		EDGES	NO. OF FACES	SHAPE OF		AXIAL DIMENSIONS
	Bases	Sides	Basal	Interfacial	Number and Length		Bases	Sides	
Sphere	0	0	0	0	0	1	—	—	* All =
Cube	90° \perp s	90° \perp s *	90°	90°	12 All =	6			All =
Regular Octahedron	—	60° \sphericalangle a	90°	Nearly 110° & 70°	12 All =	8	—		All =
Square Prism	90° \perp r	90° \perp r	90° \perp r	90°	8 Basal * + or - the 4 lateral	6			2 lengths
Hexagonal Prism	120° \sphericalangle o	90°	90°	120°	12 Basal + or - 6 lateral	8			2 lengths
Rhombhedron	—	\sphericalangle a & \sphericalangle o		\sphericalangle a & \sphericalangle o	12 All =?	6	—		2 lengths
Right Rhombic Prism	\sphericalangle a or \sphericalangle o	90°	90°	\sphericalangle a or \sphericalangle o	8 Basal + or - the 4 lateral	6			3 lengths
Right Rectangular Prism	90°	90°	90°	90°	12 of three lengths	6			3 lengths
Oblique Prism	90°	\sphericalangle a or \sphericalangle o	\sphericalangle a , \perp r & \sphericalangle o	90°	12 lengths?	6			3 lengths
Doubly Oblique Prism	\sphericalangle a & \sphericalangle o	\sphericalangle a & \sphericalangle o	\sphericalangle a & \sphericalangle o	\sphericalangle a & \sphericalangle o	12 lengths?	6			3 lengths

* + or - means more or less, greater or smaller than; = is equal, \perp right angle;
 \sphericalangle a acute angle; \sphericalangle o obtuse angle

task of arranging and grouping these facts in the child's mind. Do this by **Questions**, somewhat as follows :

What solid seems to include *all* others ? (Sphere.)

Which solids have their faces in sets of threes ?

Which their faces in fours or eights ?

Which are "right" (or *erect*) ?

Which are "oblique" on their bases ?

Which have *all* their angles right angles ?

Which have *all* their dimensions equal ?

Which have *all* faces equal and similar ?

Which have all angles right, but their edges of *two* lengths ?

Which have *two* kinds of faces ?

Are there any having edges of three different lengths ?

How about their faces ? (Three kinds.)

Which has the most faces ? What shape are the bases ?

Which has only *one* surface ?

Which has the smallest faces ? What shape is the base ?

Which have the faces all squares ? All triangles ?

Which have one kind of rectangle ? Two kinds of rectangles ?

Which have sides and bases all rectangles ?

Which have both squares and rectangles ?

Do "right" solids have any other angles than 90° ?
When ?

Which has three kinds of angles ?

Which has *no* right angles ?

Describe, in brief terms, a *sphere*.

Describe an *oblate spheroid*.

Describe from memory a *cube*.

How would I know a *tetrahedron* ?

How an octahedron ?

Pick out your *ovoid* and tell me what is peculiar about it.

What does the word *prism* mean to you ?

Describe from memory a *triangular* prism.

Describe a *square* prism.

A *hexagonal* prism.

How does a *rectangular* differ from a square prism ?

Describe an *oblique* prism.

How does a *rhombohedron* differ from a cube ?

Question in this way till the solids are familiar, and then the work is complete.

Review.—Nothing further needed.

Material put away.—Give the pupils their completed work. Put all poor and broken clay work in the jar, add a little water, and, after twenty-four hours' soaking, ram all down smooth and cover the jar tightly in a damp cellar till again wanted.

Put away all wooden models, etc.

The next step will be XXXI—Molecules.

STEP XXVII.—ANIMALS.

THE BOY LESSONS.—(*Concluded.*)

The Object of this Step.—Through the first three years' work the foundation for a wide acquaintance with animals was laid, and the fourth (Step XIX) continued this work to the use of organs and some aspects of internal structure.

My experience has been that there are always more or less new members in a class, and with a view to bringing these into line, of reviewing the past work, and preparing for comparison and classification, I have used the continuation of THE BOY (Step XIX). No new animals are introduced, but in connection with a rapid *review* is a *new view* of certain *types* among those previously looked at.

Time.—In the plan to introduce animal work at different times of the school year this step falls in late spring, say May and June. Take it up at such time of the day as the pupils need relaxation.

About fifty lessons of fifteen minutes each will be needed.

Material.—(For a supposed class of thirty.) I have usually obtained this fresh each time, but there are some things which can be kept to advantage.

1. **A cow's horn**, sawed off near the root to show the bony axis (or better as in 2).

2. **Cow's Upper and Lower Jaws.**—Get a cow's head (having short and handsome horns) of the butcher, and sink it in a pond of water till the flesh has rotted off and been removed by the water animals. Scrub it clean, and

put in some secure place in the sun to dry and bleach. Now saw one of the horns around, that the horny covering will slip off and expose the bony axis, and a very useful specimen for the cabinet will result.

3. **A Cow's Foot.**—If obtained and treated with the head, it can be easily prepared. The hoofs will come off, but can be fastened on in some way.

4. **Large feathers** from a hen's tail, to learn the parts with. Get enough so that each child can have one.

5. Of the butcher obtain **thirty hens' feet**, cut off where the feathers stop. Wash these thoroughly, spread the toes on a piece of board, secure in position with pins, and place over a furnace or somewhere so that they will quickly dry. I have had a similar collection for ten years, and they have kept perfectly and been very useful, although the fresh ones are better.

6. Have several well-dried **wings**. Spread before drying.

7. Have several good-sized **snakes in separate bottles of alcohol**. Let the bottles be of clear glass, and use sound, solid corks well rubbed with vaseline to prevent the loss of alcohol.

8. A **cast-off snake skin**.

9. A **handful** of the **ctenoid scales** of the biggest perch or wall-eyed pike to be obtained. Wash well, and dry.

Preparation of the Teacher.—This should include a careful study of the object to be reached, of the material available, and the pupils to be instructed.

Having modified this plan as may seem best, and decided what species of animals are most available, proceed to go through the lessons (as outlined) with the *animal before you*, and make such changes or additions as may seem best under the existing conditions of locality, pupils, etc.

Then *only* would I advise a teacher to attempt to give the work, as otherwise he will have so little of free-

dom for, and so little life in its presentation, as to make the lessons *very* uninteresting to all concerned.

THE LESSONS.

An outline of the work of this step will be the study of a *descending* series of types, from the cow to the sponge. This work is to be a review of the past lessons, an application of the study of The Boy, and an introduction to the grouping of animals to come later. Push the work *energetically*; but in this always guard against a few bright pupils' doing all the talking, and by individual questions, etc., draw out the timid and less ready ones. I have covered the ground easily in eight weeks' work of fifteen-minute lessons, but my class was smaller than most teachers will have, and I had other advantages to aid me which those, especially beginners, will lack. As experience is gained, the time will lessen without danger of overfeeding the pupil.

*The Cow.**

1. **Parts.**—(Have a picture or the animal before the class.)

Head, legs, body, tail, and udder.

2. **Body.**—Its shape?

Warm, or cold?

What is the whole body covered with?

3. **Skin.**—Color? Feeling? (Soft and thin.)

How does it fit?

What is the skin mostly covered with?

4. **Hair.**—Where?

Color? Shape? (Straight or curly.)

Size? (Long, short, fine, coarse.)

Which way does it run? Why? (Shed rain, etc.)

Uses? †

* A good one for milk and butter is in mind.

† "Use" always is to be understood as *to the animal*.

Is there anything else on the skin but hair ?

5. **Hoofs.**—Where ? (Covering ends of toes.)

Color ? Shape ?

Can a cow move the hoof without moving the whole toe ?

How many ? (Four on each foot.) Are these alike in size ?

Which way are the larger ones directed ?

Of what use are these ? (Protect the toes.)

Of what use are the small hinder toes ?

What do the lines on the hoof suggest as to their structure ? (Matted hairs.)

What other animals with cleft hoofs do you know of ?

Any other covering besides hair and hoofs ?

6. **Horns.**—Where placed ?

Color ? Shape ? (Conical.) How many ?

Which way do they point ?

Do they ever come off naturally ? (*Not shed.*)

What can you observe on the surface ? (Parallel lines.)

Examine the young sprouting horn of a calf and find the cause of these lines.

Are they hollow, or solid ? (Hollow caps to the bone.)

Of what use are they ? (Defense.)

What other animals have hollow horns ?

How many things grow from the skin ? (Hair, hoofs, and horns.)

Where are the horns ? (On the —.)

7. **Head.**—Its shape ?

What motions ? (Very varied.)

What parts ? (Ears, eyes, nostrils, and mouth.)

What connects it to the body ? (Neck.) Why is this long ? (To reach—?)

8. **Ears.**—Where ? How many ?

Shape ? Motions ? Directed ?

Use ? (To hear.)

9. **Eyes.**—Where placed ? Deeply set, or prominent ? Directed ? (Sidewise.)

Why thus placed ? (Consider the habits in feeding, and the dangers, in the wild state, exposed to.) How many ?

Shape ? Size ? (Not very large for the size of the animal.)

Use ? (To see food, danger, etc.)

Parts ? (Lids, ball, and tear.)

10. **Lids.**—How many ? Move which way ?

Use ? Use of lashes ? Use of tear ?

11. **Ball.**—Shape ? Motions ? Color ?

Shape of pupil ? (*Transversely oval.*)

12. **Nostrils.**—Where ? Shape of opening ? Directed ? Motion ? Use ? (Breathe and smell.)

What is there to notice about the skin of the nose ? (Moist and bare.)

How does a cow's breath smell ? (Fragrant.)

13. **Mouth.**—Where ? An up-and-down, or cross slit ?

Use ? Parts ? (Lips, teeth, tongue, and saliva.)

14. **Lips.**—Thick, or thin ? Are they sensitive to touch ? (Very.)

Why bare of hair ? (Constant wear.)

Use ? (Seize and hold food, to aid in chewing, to drink, etc.)

15. **Teeth.**—Where ? How arranged ?

What remarkable thing about the upper set ? (*No front teeth.*)

Kinds ? How many of each ? (*i.* $\frac{0-0}{3-3}$, *c.* $\frac{0-0}{1-1}$, *pm.* $\frac{3-3}{3-3}$, *m.* $\frac{3-3}{3-3} = 32$.)

What do the front teeth bite against ? (Elastic pad.)

What motion does a cow give to her head in biting off a mouthful of grass ?

How do the molars differ from ours? (Enamel is in sheets, with a cement between.)

Draw on the board the figures this enamel makes on the tooth's surface.

Test with knife or file, and determine which is hardest—enamel or cement.

Of what use can this curious alternating of hard plates of enamel and softer cement be? (Cement wears away and leaves sharp, cutting edges to grind up the coarse food.)

Do you know of other animals with no upper biting teeth?

See if you can find others having figures of enamel among softer cement. (See collection.)

16. **Tongue.**—Where? How fastened? (Back end.)

Shape? Surface? Tip?

Use? (Draw in food, move it about in the mouth, and keep it between the teeth for grinding.)

17. **Saliva.**—Should you think a cow, eating hay or grass, would need much, or little, saliva? (Much.)

Teacher tell of *huge* glands covering much of the side of the face below the ear.

Of what use is the saliva? (Moisten, soften, and change food.)

When lying down and resting, what motion do cows generally make? (Chewing.) What do they chew when not eating? (Cud.)

What is the "cud"? (A bunch of hastily swallowed food, which, having been softened in a peculiar stomach, is *brought up* again to be thoroughly chewed.)

Do you know other cud chewers?

18. What does the cow walk with?

Legs.—How many? How arranged? (Two pairs.)

What are four-legged animals called? (Quadrupeds.)

Are these pairs of legs equally strong? (No; hind legs strongest.)

What keeps them stiff and firm ? (Bones.) Are they hollow, or solid ?

What fills the hollow in the larger bone ? (A fatty substance called marrow.)

Where are a cow's bones ? (*Under skin and flesh.*)

Have they joints ? We call such "an *internal, bony, jointed* skeleton."

Do you know other animals with internal, bony, and jointed skeletons ?

What kind of joints at hip ? At shoulder ?

Remembering (Step XIX) that elbows and heels point *back*, and knees and wrists *forward*, point out a cow's elbow. Heel. Wrist. Knee.

Why do so many people take the wrist for the elbow and the heel for the knee ? (Because the shoulder and hip joints are hidden.)

What, strictly speaking, does a cow walk on ? (*Ends of fingers and toes.*)

What do we call the ends of her legs ?

19. **Feet.**—How many feet ? How many toes on each ?

How many toes does she walk on ?

What is such a two-toed hoof called ? (*Cloven.*)

Do you know other cloven-footed animals ?

What causes the rattling noise when a cow runs ? (*Toes strike together.*)

20. **Review.**—What parts have we studied ?

Skin, with its hair, hoofs, and horns.

Head, with its ears, eyes, nose, and mouth.

Eyes, with their lids, balls, and tear.

Mouth, with its lips, teeth, tongue, and saliva.

Legs, with their inside, jointed bones.

What other parts to study ? (*Tail and udder.*)

21. **The Tail.**—Where ? Its shape ? Length ? Motions ?

Uses ? (*Brush off flies.*)

22. **The Udder.**—This is a group of huge glands to separate milk from the blood. Is it not truly *wonderful* that white milk can be formed from red blood, and so much of it each day! How much milk will a good cow give?

Has her *food* anything to do with it?

Yes, a cow is really a milk-making machine. If you supply a good cow with plenty of proper food you are sure of plenty of milk.

What is the shape of a good udder? (Should run well forward rather than deep.)

How many teats has a cow? (Four.)

What are these for? (The calf to suck.)

Do you know other milk-giving animals?

23. Where does a cow **live**? (On land.)

24. What is her **home** called? (Stable or barn.)

25. How does she **move**? (Walks or runs.)

In what position? (Horizontal.)

What keeps her back straight?

26. **Backbone.**—What is this? (A row of bones strongly joined to each other, and extending from the head to the end of the tail.)

Do you know of other backboned animals?

27. How does a cow **sleep**? (Lying down, with head resting on her side.)

28. What does she **eat**? (Vegetable food.)

How does she get the food into her mouth? (Tongue and lips.)

29. Does she need anything besides vegetable food? (Air and water.)

30. Can she **talk**?

How does she let us know that she wants food? (Actions and lowing.)

When she wants her calf?

When angry, excited, or in pain? (Bellow.)

31. What is the **young** of a cow called? (Calf.)

What sounds does he make ?

Does he resemble his mother ? (Yes.)

What does he live on ? (Milk.)

32. Of what **use** is the cow to us ? (Milk and flesh.)

What kind of a food must milk be, to be able to supply all the wants of a growing calf ? (Perfect food.)

What does milk contain ? Fat (butter), sugar, casein (cheese), and water.

Which of these are *heating* ?

Which is able to build muscle and nerve ?

The Hen.

1. **Parts.**—(Have a hen or good picture of one.)

Head, body, legs, wings, and tail.

2. **Body.**—Shape ? (Egg-shaped.)

What is the body covered with ?

3. **Feathers.**—What do they grow from ? (Skin.)

Are they arranged orderly, or scattered ? (See picked body.)

Parts of a feather. (Give each pupil a large one.)
(Quill, shaft, and vane.)

What can you say of the quill ? (Transparent, hollow cylinder, stiff and very light.)

Of the shaft ? (Opaque, angular, solid, and tapering to the end.)

Of the vane ? (Many little plates with fringed edges which interlock and make the feather resist the passage of air.) Will they *relock* if gently pulled apart ? (Try.)

Do all these plates lock together ? (No, the soft lower ones do not.)

These are called "down." What *use* for down ? (Warmth.)

When our clothing wears out we get new clothes.

Did you ever see a hen who needed a new dress ?

How did she look ?

How does she get rid of the old suit ? (Molts.)

What do we call the young feathers? ("Pin" feathers.)

Why does the cook "sing" a plucked hen? (Hair-like feathers.)

What do we call the large feathers of wings and tail? (Quills.)

Now name as many kinds of feathers as you can.

Is *all* the body covered with feathers? (Comb, wattles, bill, and legs.)

4. **Legs.**—Where are the legs? (Under the middle of body.)

How many? (Two.) Are they *stiff*? What makes them so?

Are the bones *jointed*? Where are the bones? (Under skin and flesh.)

What kind of a skeleton has a hen? (Internal, bony, and jointed.)

What have you ever observed of the bones of birds? (White and hollow.)

What is the hollow filled with? (Air.)

(Show a plucked bird.)

Which way do heels bend? (Backward.) And knees? (Forward.)

Now look carefully, and tell me what the "legs" every one speaks of really are! (*Feet!*)

What is the "drumstick"? (Leg.)

Below the leg is—? (The foot.) This upright part is the *tarsus*.

What does a bird walk on? (Its toes.) As a cow? (No; on the whole toe.)

What is the tarsus covered with? (Scales.) Do they overlap?

5. **Toes.***—How many has the hen? (Four.)

How are these arranged? (Three in front and one behind.)

* Have specimens for pupils.

The hind toe is the "first," the inner toe "second," middle toe "third," and outer toe "fourth."

Which toe is directed backward? (First.)

Which forward? (Second, third, and fourth.) Which is the shortest toe?

How many small bones in the first? (Two.) In the second? (Three.) In the third? (Four.) In the fourth? (Five.)

What are the toes covered with? (Scales.) How do the scales look and feel?

Each toe ends in—? (A nail.)

Are these nails retractile, like a cat's? (No.)

Of what use are they? (Scratch up food.)

Are her toes webbed? Are they all on the same level? (Hind toe *highest*.)

Look on the cut end of your specimens (if fresh) for the silvery white tendons. Get hold of these and *pull*. (Work the toes.)

Where is the muscle which works *our* toes? (In the leg.)

Where is the muscle to work the hen's toes? (In her leg or "drumstick.")

When she raises her foot in walking, what happens to the toes? (Bend.)

What happens to her toes when her legs bend? (Clasped together.)

Of what use is this to the hen? (Clasps the perch, even when asleep.)

What uses for legs and feet? (Scratch, walk, perch, etc.)

Is there any other way that she can move? (Fly.) With what?

6. **Wings.**—Where are the wings attached? How many?

What are they covered with? How are the feathers arranged?

What shape below? (Concave.) Above? (Convex.)

What general shape or outline? What motion?

Which edge is stiffest?

As the wing is moved down what must happen? (Bird moves or air escapes.)

Will it escape over the front edge, or hind edge? (Hind.)

What motion will this give the bird? (Push forward.)

What muscles move the wings? (Breast.)

Does a hen fly often? (No.)

What color is the meat of the breast? (White.)

What color is the meat of the legs? (Dark.)

Who can think of the reason? (Legs used most.)

What does a hen do with her wings when not in use? (Folds them by her sides.) Do they then reach beyond her tail?

7. Tail.—Where? Composed of what? (Large, stiff feathers.)

How many quills in her tail?

What motion can she give these?

8. Oil Glands.—Look on a plucked fowl for two bean-like bodies on the back, at the root of the tail. Press one of these. What comes from it? (Oil.) The hen has her oiling apparatus all in one place. How does she manage to get it on her feathers? We shall see as we study the

9. Head.—Where? (On end of neck.)

General shape? Can a hen turn her head straight back?

Parts. (Comb, wattles, eyes, ears, and bill.)

10. Comb.—Where? Shape? Color? Is it always equally bright? (Brightest when laying, or facing danger.)

Can you think of any use the comb is to a hen? (Or-

namental, and perhaps to awe an enemy by its vivid color.)

11. **Wattles.**—Where? Shape? Color? Use? (Same as comb.)

12. **Eyes.**—Where? (*Sides* of head.) Does a hen usually see a worm with both eyes at once?

Are they deeply set?

Are they large, or small, for the size of the animal? (Large.)*

Parts? (Lids, ball, and tear.)

How many lids? † (Three.) Which way does the third lid move? (Across.)

How many times a minute does she wink? (Count.)

What is the shape of the ball? Of the pupil?

Can she turn her eyeballs? Do both move together like ours?

Of what use are the eyeballs? (See with.)

And the lids? (Protect and moisten the ball.)

Can birds see *well*? (Have *remarkable*, almost telescopic sight.)

13. **Ears.**—Has the hen any external ears?

What indicates where they are? (Circle of feathers and hole.)

Where are these holes located? How many?

Use? (To hear with.)

Have clean heads for the class to examine

14. **Mouth.**—What do you call a bird's mouth? (Bill.)

Which way does it open? (Up and down.)

What is the bill made of? (Horny matter.)

Its shape? (Somewhat conical.) How many parts to it? (Two.)

* $\frac{1}{280}$ of the entire hen in one I measured, while a 150-pound man's would be less than $\frac{1}{1200}$.

† Gently touch a hen's eye with a feather till she moves this third lid.

The upper outline or "bridge" is called the *culmen*.

Is the culmen of a hen's bill straight? (Curved.)

Is the *gape* (opening) straight, or curved?

Does the gape or opening extend to below the eye?

Are the edges of the bill notched? (No.) Are they sharp?

Which half shuts inside the other? (Lower.)

Which is greatest, the *depth* or the *width* of the bill? (Depth.)

Such a bill as the hen's is said to be "short and stout."

What is the bill for? (Pick up food.)

Does she *chew* the food? Examine the tongue and see if it is adapted for *tasting*. (No.)

How does a hen select her food? (Sight.)

15. **Nostrils**.—Where are these? (At base of bill.)

What covers them? (A fleshy scale.)

Of what use are they? (Mainly to breathe through.)

16. **Neck**.—What is most noticeable about a bird's neck? (Length and flexibility.)

Why is it so long and flexible? (So that the bird can reach food, and all parts of its body to preen and oil its feathers.)

17. Is a hen a land, or water, bird?

18. How does she move? (Walks, runs, flies, etc.)

How is the body held in walking? Running? (More forward.)

In flying? How in sleeping? (Head under wing.)

19. What kind of **food** does she eat? (Miscellaneous.)

How is the food taken? (With the bill.)

How is the food ground up and prepared? (Show a "crop" with its softened contents, and open a gizzard and show its thick muscular walls, and gravel to grind up the food.)

20. What does she **drink**?

How? (Water in bill, and then throws the head up for water to run down.)

Why does she not drink as we do? (No fleshy lips.)

21. What does she **breathe**? (Air.) What with? (Lungs.)

Yes, and these are connected with the hollow bones, so that it is said * a bird can breathe through a broken bone when the windpipe is closed.

How many times does she breathe a minute? (Count.)

How does this rapid breathing affect the heat of the body? (*Hot*.)

Of what color is the blood? (Red.)

22. What is her **home** called? (Nest.)

Where made? Of what material? What for?

23. **Eggs**.†—Color? Shape? (Typical.) Surface?

Parts? (Shell, white, and yolk.)

What can you say of the shell? (White, hard, brittle.)

Drop a bit of shell in hydrochloric acid. (Effervesces!)

Place a small egg in a tumbler of water and add a few c. c. of acid. In a day or two the lime will be removed and the "soft-shelled" egg can be got through the neck of a bottle, or other "impossible" place to get an egg through "without breaking it."

What else have you learned? (Shell is a tough skin with lime in it.)

Hold some bits of shell up to the light. (Porous.)

What lines the shell? (Two skins.)

When you open a hard-boiled egg what do you notice at the large end? (Hollow place.) This is filled with—? (Air.)

Does the hard yolk seem in the *middle* of the white? (Nearer one side.)

Mark "Up" on one side of an egg and boil it in ex-

* Owen, p. 118.

† See Owen's Comparative Zoölogy, pp. 193-204.

actly that position. Where is the white *thinnest*? (Upper side.)

Who has seen a dish of eggs broken for cake? Do the yolks float?

Do they keep any particular position? ("White spot" side *up*.)

All of these things are of importance to this *wonderful* thing called an egg!

How are a hen's eggs laid? (One at a time.)

How many does she lay? (If left to herself, as many as she can cover.)

24. **Setting.**—What change in the habits of the hen? (Stops laying, sets, etc.)

Does she feed? Drink? Dust? (Same as ever, but *hurriedly*.)

Why does she hasten back? (Eggs must not get cold.)

How long must she continue to set? (Twenty-one days.)

How is she protected from enemies while on the nest? (Colors.)

What traits of character does she display? (Patience and courage.)

After the twenty-one days are passed, from the eggs come what?

25. **Chickens.**—How do these get out of the shell? (Pick an opening.)

How are they clothed? (Down.) Do they resemble the hen? (Yes.)

Can they soon run about? And pick up food?

What do they eat?

How do they call the hen? ("Peep, peep!")

Where do they sleep? What does the hen do at such times? (Gathers them under her wings and quiets them by "crooning.")

What is the use of so *much* food in the egg? (To feed the growing chick so that it may be able to run about and feed itself when hatched.)

26. How does the hen call her brood? ("Cluck, cluck!")

What sounds when she has food? (Chuckle.)

When danger threatens? (Warning cry.)

When hurt herself? (Squawks.)

When an egg has been laid? (Cackles.)

*The Snake.**

Have several medium-sized snakes in clean fruit jars to pass around; also, as the class gains courage, have one or two to pass about from hand to hand.

1. **Parts?**—(Head, body, and tail.)

2. **Head.**—Shape? (Note the graceful taper in our harmless snakes.) Motions? Covered with? (Broad scales.)

Parts? (Eyes, nostrils, and mouth.)

3. **Eyes.**—Where placed? (Note how *high up* on the sides of the head.)

How many? Shape of ball? Pupil? (Usually *round* in harmless snakes.)

Size? Motion? Use?

Are there any lids?

4. **Nostrils.**—Where placed? How many?

Shape? Directed? Use? (Snakes seem to have an acute sense of smell.)

5. **Mouth.**—Where? An up and down or a cross slit?

Motion? Use? (To take food.)

Who has ever seen a snake swallowing anything? Tell *us* about it.

How do you suppose it could get such a big thing in its small mouth? (Bones of head are loosely connected by gristle, and can expand and stretch enormously.)

Parts of mouth? (Lips, teeth, tongue, and saliva.)

6. **Lips.**—What about these? (Thin and delicate.)

* Any common, harmless kind.

7. **Tongue.**—Where fastened ? (Behind.)

What can you say of it ? (Slender, forked, and dark-colored.)

Can the snake put it out when the mouth is *shut* ?

Use ? (To spread the saliva on its food before swallowing and as a means of *defense*, the rapidly darting tongue adding much to the threatening appearance of the animal.)

8. **Teeth.**—Where ? (Feel with a pencil point.)

How arranged ? (In a single row around the jaws.)

Shape ? (Points, curved backward.)

Use ? (To hold food and aid in swallowing live prey.)

9. **Saliva.**—Is this abundant ?

Why needed ? (To lubricate the food in swallowing.)

10. **Ears.**—Can you see any ?

Do snakes seem to have good hearing ? (No.)

11. **Body.**—Shape ? What can you say of the legs ? (*None!*)

Is it stiff or flexible ?

What is it covered with ?

12. **Skin.**—Is the skin loose or tight ?

What is the skin covered with ?

13. **Scales.**—How arranged ? (In regular rows.)

Colors. (Note the way these are arranged to harmonize with the snake's surroundings, and so *protect* it.)

What shape are the scales ?

Has each one a ridge through the middle, or is it smooth ?

How many rows, counting over the back ?

How about the scales on the belly ? (Large and broad.)

Do the scales ever get worn and need renewing ?

How is it done ? (A new set of scales grows under the old, which then become loose, split away at the mouth, and the snake, by getting in some close bushes or coiling

among grass, strips off the old skin (slough), turning it inside out.)

14. **Tail.**—(Simply a continuation of the cylindrical body.)

15. Where does this snake **live**? (Depends on——?)

16. How does it **move**? (Let it crawl through the hands, so as to feel the play of the ribs which, like *many* feet, urge it on. Snakes mainly move by curving the body and *pushing* with the curves. They make very little progress on a smooth surface, where there is nothing to push against.)

Has a snake bones? Where are they? (*Under* skin and flesh.)

17. In what position is the body when it moves?

18. What do snakes **eat**? (Insects, mice, young rats, gophers, frogs, etc.) How does it seize the prey? (With its mouth.)

And then chews it? (No, swallows it *whole*!)

Consider the food and tell me, are these snakes useful to man or not? (Destroy vermin and are very helpful.)

Should they be killed then? (*No!* harmless, useful, and beautiful creatures should *not* be killed in sport.)

How can we tell the poisonous ones? (Usually have flat, triangular heads, small necks, and thick, stumpy bodies.)

19. Do snakes **drink**? (Yes, they need plenty of water.)

What do they *breathe*? (Air.) Are they warm-blooded or cold-blooded?

20. Do snakes *make* a home?*

* Snake "holes" are a *myth*. I never saw a snake *make* one, nor even enter one of the perpendicular holes in our prairies, nor can I conceive of the delicate lips and jaws being used for any such purpose as digging a hole in the earth. That they live in logs, clefts in the rock, etc., is true.

21. **Eggs.**—Who has ever seen any? Several times I have turned over a sod in the garden or field and found twelve to twenty longish, soft-shelled, white eggs stuck together in a kind of string. They were about as large and long as the first joint of my thumb. No snake was about. What hatched them? (Sun.) They had a large yolk, like a hen's egg. Judging from that, would you expect the young to be able to run and feed when hatched?

Were the smallest snakes you ever saw shaped like their mother? (Yes.)

22. Can a snake *talk*? (Hiss.)

The Frog.

Choose some common kind.

Have several in an aquarium for the school to watch for some days. During the study pass these around the class.

1. **Parts?**—(Body, head, and legs.)

Shape of the body? (Pointed behind.)

2. Has the frog a **skin**?

Its color above? Below? What use is this coloring? (Protection.)

How does it fit? (Loosely.)

How does it feel? (Cold and smooth.)

Is it dry or moist? (A frog will *die* if its skin is kept dry long.)

3. Is there anything growing from the skin? (*Nothing.*)

What shall we call such a skin? (Naked.)

4. **Head.**—Shape? Motion? (Very little.)

Parts? (Eyes, ears, nostrils, and mouth.)

5. **Eyes.**—Where? (Almost on top of the head.)

Are they prominent or deeply set?

What shape? Color? Large or small? Use?

6. **Lids.**—How many? Which way do they move?
(*Eye seems to be drawn in.*)

Why is the lower one transparent?

7. **Eyeball.**—Its shape? Can the frog move it? Shape of the pupil?

Does the size of the pupil vary in passing from strong light to shade?

8. **Ears.**—Where? Any external opening?

Does your own experience indicate that we can hear *through* things?

Have you any reason to think the frog can hear with closed ears?

Why would openings or projecting ears be inconvenient? (So much in the water.)

Who has been in swimming? How do noises sound when the head is under water? (*Very loud and distinct.*)

How does this apply to a frog?

9. **Nostrils.**—Where located? (*High up on end of snout.*)

How many? Shape of opening? Can the opening be closed when under water? Use? What does it breathe? (Air.)

Is a frog warm- or cold-blooded?

10. **Mouth.**—Where placed? A cross or an up and down opening?

Motions? Size? Use?

Parts? (Lips, tongue, teeth, and saliva.)

11. **Lips.**—What can be said of these? (*Thin and delicate.*)

12. **Teeth.**—Where located? (*Upper jaw alone.*)

Size? (*Small.*) Use? (*Aid in holding live prey.*)

13. **Tongue.**—Where? How fastened? (*In front!*)

Shape? Tip? Surface? (*Sticky.*)

Motion? (*Thrown forward with great rapidity.*)

Use? (*Catch insects, etc.*)

How is the food swallowed? (*Whole.*)

Of what use is the saliva ? (Swallow food easily.)

14. What do you notice about the frog's *neck* ? (Almost none.)

15. **Legs.**—How many ? How arranged ? (Pairs.)
Are they alike in shape ?

Are they stiff in any part ? What makes them so ?

Where are the bones ? (*Under skin and flesh.*)

Have the legs joints ?

16. **Forelegs.**—How many joints in each ? (Two.)

What end the forelegs ? (Hands.)

How many fingers on each ? (Four.)

Which is the longest ? (Third.) The shortest ?

Have they nails on the end ? (None !)

Are the fingers webbed ? What are they (the hands) used for ?

17. **Hind Legs.**—How many joints in each ? (Three.)

Which is the *knee* ? Which the *heel* ?

How do the hind legs compare with the forelegs ? (Longer and stronger.)

How many toes ? (Five.) The shortest ? Longest ?

Are they webbed ? Have the toes nails ? (None.)

What are these powerful hind legs for ? (Leap and swim.)

What is remarkable about the frog's skin ? (Perfectly *naked.*)

18. Where does the frog **live** ? (Both on land and in the water.)

On land it hops. In the water it swims.

Who has observed the habits of a frog when it is alarmed and jumps into the water. (Swims off a little distance, and then returns to some bunch of weeds or grass and rises till the tip of the nose and the eyes are just out of the water, and then it rests. This is all done so quietly that it is rarely observed.)

Why are its eyes and nostrils set so high on the head ?

19. What does the frog **eat** ? (Insects mainly.)

How does it catch its prey? (Sticky tongue.)

Are frogs useful or injurious? (Useful.)

20. What **sounds** does a frog make? When?

21. **Eggs**.—Show some to the class.

What are these? Color? Shape? Number?

Where are they laid? (On weeds in the water.)

When? (In early spring.)

Are they cared for by the mother frog?

Is the yolk large or small? (Small.)

Now take several wide-mouthed dishes (milk crocks are good) and place a bunch of eggs and some water plants in each. Go on with other work till the eggs have hatched.

Let several pupils keep a "diary" of each dish.

22. I thought these were *frog's* eggs! Do these little things look like *frogs*?

What can you tell about them? (Tails, bushy gills at sides of head, big heads, two eyes, and a little mouth. They live in the water all the time and swim with their tails. Certainly this is not froglike!)

We will wait and see! As time goes on record the sprouting of the hind legs, of the forelegs, the disappearance of the tail, etc.

Were they frog's eggs? Who will tell me the life history of a frog? (Egg, tadpole with gills, etc.)

What about the egg indicated this imperfect condition at first? (Small yolk could not feed the little frog in the egg long enough.)

The Fish.

Gold fish will be easy to keep and study, but any live fish that can be kept before the class for a while will do.

Wide dishes, with a wire-netting guard to prevent their jumping out, and from four to six inches of water have proved much more satisfactory than the narrow-

mouthered aquaria. Feed only such food and in such quantity as the fish will snap up entire.

1. **Parts?**—(Head, body, and fins.)

2. **Body.**—Shape. (Note the elegant curves of least resistance to the water.)

What is the body covered with?

3. **Scales.**—These grow from? (Skin.)

Colors of scales? Can you imagine any use for these colors?

Arrangement of scales? (Regular rows.) Observe the "lateral line" extending from head along the side to the root of tail fin.

How many scales are there in this lateral line?

If you were making an artificial fish, would you begin at the head or tail to put on the scales? Why?

What shape is each scale? Is the edge next the skin smooth or toothed? What kind of a surface has each scale?

Can a fish move its scales?

Can you find parts destitute of scales?

4. **Head.**—Deep or wide? Gradual or abrupt slant on top?

Has it, as a whole, much motion? (No.)

Parts? (Eyes, gill covers, nostrils, mouth.)

5. **Eyes.**—Where placed? Prominent or sunken?

Shape? Size? Use? Parts? (Ball.)

6. **Eyeballs.**—Shape? Motion? Color? Shape of pupil?

Any lids? (No.) Tear? (No.) Why are none needed?

7. **Gill Covers.**—What are these? (Several horny flaps covering openings in the sides of the head.) What motion do they have?

What are under and protected by them? (Delicate, red gills.)

How many of these gills under each?

What makes them so red ? (Blood.)

What are they for ? (Instead of lungs.)

But how does the fish get air ? Here is a quart jar entirely full of pond (or spring) water. Can you see any air in it ? (No.)

Let us heat it over this register (better, plunge into hot water.)

See the bubbles of air rising and gathering at the top !

Where does the blood in the gills get oxygen ? (From the water.)

Does the blood give out CO_2 as our lungs do ? (Test some water which fish have been in with lime-water, and the milky coloration will show CO_2 .)

How does the fish keep the water flowing over the gills ? (Opening and closing mouth, forward motion when swimming, and by flapping side fins when at rest.)

8. **Nostrils.**—Where ? How many ? Shape ? Use ? (Smell.)

9. **Mouth.**—Where ? A cross or up and down slit ?

How far back does the slit extend ?

Large opening or small ? Is either jaw the longer ? Which ?

What motion to jaws ?

Use ? (Take in water to gills and seize prey.)

Parts ? (Lips, teeth, tongue.)

10. **Lips ?**—(Hard and firm.)

11. **Teeth.**—Where ? (Examine by feeling ; they may be on jaws, tongue, or roof of mouth.) What kinds ? Few or many ?

Which way do they point ? Use ? (Seize and hold live prey.)

12. **Tongue.**—Where ? What kind of a substance ? (Hard.)

Where fastened ? Shape ? Motion ? (Very little.)

Considering the way fish swallow their food at one gulp, is the tongue probably of much use for *taste* ?

13. **Fins.**—How many? Where placed? (This is *very* important.)

Teacher draw the fish on the board and point out the *dorsal* (back), *pectoral* (sides of head), *ventral* (on belly), *anal* (below, in front of tail), and *caudal* (tail) fins.

How many dorsal fins? If one, is it deeply notched?

Is the membrane supported by *spines* or "soft rays"?

How many spines? How many soft rays?

Is there a skinny (adipose) fin near the tail?

How many spines and soft rays in the pectoral fins?

Where are the ventrals placed?

How many spines and soft rays in each?

How many in the anal fin? Does it extend to the caudal?

Is the caudal forked or rounded? Does the backbone seem to end at the center or run into the upper lobe of the caudal?

What are the different fins for?

14. Where do these fish **live**?

15. Do they make a **home** of any kind? (No.)

16. How does a fish **move**? (Swim, jump, dart, etc.)

What position is the body in when moving? (Horizontal.)

Has it a backbone? With joints? (Remember fish at the table.)

What kind of a skeleton has it? (Internal, bony, and jointed.)

17. What does it **eat**?

How does it take the food?

Does it chew its food?

18. Does a fish make any sounds? Can it hear?

19. Who has seen **young fish**? Do they resemble the mother?

The eggs are laid in the water and neglected by the mother.

What do you think happens to many of them?
(Eaten.)

Yes, many water animals are fond of eggs and eat all they can find. How do fish manage to avoid destruction. (They lay a great many eggs, *millions* in some cases, and so enough escape and hatch to keep the waters supplied with fish.)

20. Who can think of any **resemblance between the six animals** we have studied? (Boy, cow, hen, snake, frog, and fish.)

1. All have an **inside, bony, jointed skeleton**.

2. All have a **backbone**.

3. The **organs**, eyes, ears, limbs, etc., are **paired**, and the two sides of the body alike.

*The Moth.**

Should it be impossible to get caterpillars and cocoons, postpone this lesson till such time as they can be had. Some butterfly will do just as well, except that its caterpillar spins no cocoon.

1. **Parts?**—(Head, thorax, abdomen, wings, and legs.)

Into how many parts does the body of the moth seem divided? (Three.)

2. **Head.**—Shape? Motions? Covering? Parts? (Eyes, antennæ, tongue.)

3. **Eyes.**—Where? Size? Color? Surface? Are they simple or compound? (Compound. The simple eyes on the top of the head will probably not be seen.)

What is a "compound" eye? †

Can the eyes be moved? Their use?

4. **Antennæ.**—Where are they fixed? Shape? Motion? Number? Use? (For feeling and smell.) Are they *clubbed*? (Not in *moths*.)

* *Cecropia* or other large, common sort.

† Show drawings and explain. See Orton, p. 182, or other zoölogy.

5. **Tongue.**—Where fastened? How held when not in use? (Coiled.)

Length? Motion? Use? (To draw up the nectar of flowers.)

6. **Thorax.**—Where is this? (Between head and abdomen.)

What shape is it? Covered with? Stiff or not?

What grow from it? (Two pairs of wings and three pairs of legs.)

7. **Wings.**—How many? Where placed? How held when the moth is at rest? Which overlap the others?

What use? Are they equal in size? Which largest?

What are they covered with? (Loose *scales*.) Is there any *order* in their arrangement?

How stiffened? (“Veins,” really air tubes.*)

8. **Fore Wings.**—Shape? Front margin? Hind margin?

How are the principal veins arranged?

Describe the colors above? Below?

Are there joints in them? (No.)

9. **Hind Wings.**—Shape? Front margin? Hind margin? Why is the hind margin flexible?

How are the principal veins arranged?

Describe the colors of upper side? Of lower?

Any joints in them?

10. Remembering that this moth lives on trees and hides among the crevices of bark and small limbs, can you see any use in the position of its wings when at rest?

In the colors of the upper or lower surfaces of the wings?

11. **Legs.**—How many? (Six.) Growing from? (The thorax.)

How arranged? (In pairs.) Use? (Walk and climb.)

12. **Front Legs.**—Which way directed? How many joints?

* See Orton, pp. 114, 115.

What end them ? (Feet.) Can you count the joints in each foot ?

What is the last one ? (Pair of hooks.)

13. **Middle Legs.**—Which way directed ? How many joints.

How many joints to the feet ? The last one is—— ?

14. **Hind Legs.**—Which way directed ? Joints ?

Joints in feet ? Last joint is ?

15. **Abdomen.**—Shape ? Covered with ? Colors ?

Motion ? Any parts ? (*Joints*, but they can hardly be counted.)

16. Where does this moth **live** ? (On trees and in the air.)

How does it *move* ? (Mostly flies.) When ? (At night.)

What does it **eat** ? (Nectar of flowers.)

It seems fond of that from deep, tubular flowers. How does it get it ? (With long tongue.) Does it get a meal in *one* flower ?

Of what use are these visits from one flower to another to the flowers themselves ? (Carry pollen. See Morning Glory, Step XXIII.)

17. What part have we not yet considered ? (*Nose*.)

Have you seen anything like a nose ? (No.)

How do moths breathe air ?

They do this by openings along the *sides* and not through the mouth.

These we shall see better in the caterpillar.

18. What did these moths come from ? (Long, brown, silken cocoons.)

What made the cocoon ? (Caterpillar.) Let us study one of these.

The moth lays eggs. Where ? (On food-plant.)

How does she know what the young eat ?

These eggs hatch by what heat ? (Sun.) Into ? (Caterpillars.)



19. **Caterpillar.**—Colors? Why *these* colors?

Parts? (Body, head, and feet.)

How many parts (or rings) to the whole body? (Thirteen.) What covering?

20. **Head.**—Color? Parts? (Simple eyes and jaws.)

How many eyes? Where placed? What for?

Which way do the jaws open? (Side to side.) Use? (Gnaw leaves, etc.)

Is the head movable?

21. **Body.**—Composed of how many segments? (Twelve.)

What is the first segment called? (Head.)

Second segment. Size? Color? What appendages? * (Pair of legs and breathing-hole.)

Third segment. Size? Color? Appendages? (Pair of legs.)

Fourth segment. Size? Color? Appendages? (Pair of legs.)

Fifth segment. Size? Color? Appendages? (Only a breathing-hole.)

Sixth segment. (Same.)

Seventh segment. Size? Color? Appendages? (Pair fleshy, hooked legs and breathing-hole.)

Eighth segment. Size? Color? Appendages? (Same.)

Ninth segment. Size? Color? Appendages? (Same.)

Tenth segment. Size? Color? Appendages? (Same.)

Eleventh and twelfth segments. Size? Color? Appendages? (Only breathing-holes.)

Thirteenth segment? Size? Color? Appendages? (Pair of fleshy legs.)

How many jointed legs? (Six.) How many fleshy legs? (Ten.) How many together? (Sixteen.)

How many breathing-holes? (Twenty-two.)

Is a caterpillar warm or cold blooded? (Cold.)

* These are not the same in all caterpillars.

How does it move? (Crawls.)

Has it any *bones*? (No.) Joints? (Between each ring and on fore legs.)

Where does the skeleton of moth and caterpillar seem to be? (*Outside!*)

22. **Food?**—What does it eat? (Leaves.)

As it grows, how does it manage with its skeleton *outside*? (Sheds its skin or *molts* frequently, four or five times, and after each molt swells out and grows rapidly for a time, and then waits till the next molt before growing again.)

23. When fully grown a caterpillar stops eating and hunts for a place to spin its cocoon. What place does it usually select?

What is a cocoon made of? (Silk.)

Where does the silk come from? (An opening below the jaws, out of which flows a fluid that almost instantly hardens into a thread of *silk*.)

Now have such of the pupils as have seen it done, describe the process of spinning a cocoon.

24. Inside this silken nest, what happens to the caterpillar after the cocoon is made? (Turns to a brown, mummy-like *pupa!*)

Does this show life? (A little.)

Does it look like a moth? (No.)

Those who have examined pupæ tell us that nearly all traces of the caterpillar seem to dissolve away, and from the liquid contents grows—what? (The *moth!**)

Who taught the moth to lay her eggs on some particular plant?

What prompted the untaught and inexperienced caterpillar to select a suitable spot and there spin a cocoon?

* Orton, note 118, p. 390.

Crayfish, or Crab.

This study should come in *early* spring, when crayfish with young can be found.

I should advise taking the study of mother and young, and *then* placing one family in each of two or three wide dishes and letting the pupils feed and rear the young, which will be very useful to distribute to the class when, at this later date, the study is completed.

If fresh specimens can not be had, use those prepared as suggested in Step IX with the preserving fluid.

(Huxley's Crayfish should be read—at least the first one hundred and seventy-three pages—and should be used by each teacher, *specimens in hand.*)

1. **Parts?**—(Body, legs, and abdomen.)

2. **Body.**—How does it feel? (Hard, smooth, and cold.)

What shall we call the covering? (Shell.)

Its color? Drop a bit of dry shell in hydrochloric acid? (Effervesces.)

What is left? (A bit of tough skin.)

What is the covering then? (A tough skin hardened with lime.)

Where does the skeleton seem to be? (Outside.)

Has the crayfish a *head*?

What seems to have happened to it? (United with the body.)

What did we call the second part of the moth? (Thorax.)

When we find the head and body united we call it a *head thorax*.

3. **Head Organs?**—(Eyes and antennæ, as seen from above.)

What is peculiar about the eyes? (On movable stalks.)

Are they simple or compound eyes? (Compound.)

Have they eyelids? (No.)

4. **Antennæ.**—How many? (Two long and four short.)
 What shape? How constructed? (Many joints.)
 Which way can they be directed? (All ways.)

As you observe the crayfish employ them, what *use* do they seem to be? (Feel.)

Scientific men have discovered that the short antennæ are also organs of *smell* and *hearing*.*

5. **Mouth.**—Has the crayfish any mouth? Where is it? (Under side.)

Turn the animal on its back and see the mouth.

Which way do the jaws and parts about it move? (Side to side.)

How many parts are there around the mouth? (Ten in five pairs.)

Can you make out the use of any of them?

Yes, they aid in holding and tearing up the food ready to be swallowed.

6. **Food.**—Do any of you know what this is? †

How is live food caught? (By big pinchers or claws.)

How chewed up? (By foot jaws and hard mandibles.) Could we examine the stomach we should find some hard, grinding teeth *there*!

7. **Legs.**—What else do you notice on the underside? (Legs.)

How many? (Ten.) How arranged? (In five pairs.)

Let us study these one by one, beginning with the big front ones.

8. **First Pair of Legs.**—What are these usually called? (Big claws.)

* Huxley, pp. 114–117.

† Huxley, p. 9, gives an extended bill of fare for the English crayfish. Our American ones, as far as I have observed, eat small fish, pollywogs, earthworms, and decaying flesh, especially of *fish*. They seem to play an important part as *scavengers* in our ponds and rivers.

Which way are they directed ?

Where attached ? How many joints in each ? (Six.)

Gently move the leg, and observe the varied motion of these joints.

What peculiar motion has the sixth joint ? (Like a thumb.)

What is peculiar about the fifth ? (Prolonged into a "finger" to meet the sixth.)

What do you notice about the inner edges of the fifth and sixth ? (Rough.) About the tips ? (Hooked.)

What is the use of these roughnesses ? (Hold things better.)

9. **Second Pair of Legs.**—Where are these ? (Close behind the first.) Which way directed ?

How many joints ? (Seven.) What is noticeable about the sixth and seventh ?

10. **Third Pair of Legs.**—Where ? Directed which way ? Number of joints ?

How about the sixth and seventh ? (Like a thumb and finger.)

11. **Fourth Pair of Legs.**—Where ? Directed which way ? Number of joints ? The seventh ?

12. **Fifth Pair of Legs.**—Where ? Directed which way ? Number of joints ? The seventh ?

What use for these five pairs of legs ? (Walk, fight, catch food, etc.)

Which can best be used to take food ? (First three pairs.)

13. **Abdomen.**—Where ? (Attached to hinder end of head thorax.)

Shape ? (Convex above and flattened below.) Its motion ? (Up and down.)

How many segments in it ? (Seven.) How arranged ? (The hind edge of each overlapping the front edge of the next.)

How connected ? (By tough, flexible skin.)

14. **First Segment.**—Note its shape, comparative size, edges, etc.

Has it any appendages? (A pair.)*

15. **Second Segment.**—Note as above. Appendages? (A pair.)

16. **Third Segment.**—Note as above. Appendages? (Pair of swimmerets.)

How are these swimmerets constructed? What motion have they?

17. **Fourth and Fifth Segments.**—About the same.

18. **Sixth Segment.**—What grow from it? (Two *broad* swimmerets.)

Turned which way? How many pieces in each?

What motion? (Downward, like the last segment.)

19. **Seventh Segment.**—Shape? Size? Any appendages? (No.)

Joints? (One.) Motion? (Down.) This and the four flaps of the sixth segment's swimmerets together form the "telson."

What is the use of the telson? (To swim *backward* with.)

Of what use are the other swimmerets? (Gently to paddle *ahead*, and in the mother crayfish to carry the eggs and young.)

20. **Breathing.**—When a live specimen is still, watch closely and see if there is any motion to the overhanging edges of the back. With a glass tube or dropper drop a little colored fluid into the water just by the side of the first segment of the abdomen. Does it show a *current* in the water?

Which way? (*Forward*, under the sides of the thorax.)

Watch in front by the sides of the head and see a

* What these are depends on sex, and will be "hooks" in the male and "swimmerets" in the female.

fluttering organ. Under the broad, overhanging margins of the thorax are many pairs of delicate *gills*, in which the blood is purified.

What does the crayfish breathe? (Air in water.)*

Where is it taken in? (Behind.) And is let out? (In front.)

How is the water changed when the crayfish swims backward?

When lying still? (The little fluttering paddles keep drawing it out in front, and of course more has to come in behind.)

What similar device in another water-breathing animal? (Pectoral fins of the fish.)

21. Where does the crayfish live? (In water of streams and ponds.)

When a pond dries up, as the sloughs of the wide prairies do almost every year, how does it manage? (Digs a well.)

As the water keeps sinking in the soil? (Digs deeper and deeper.)

What does it dig with? (Big claws.)

When? (At night.)

How does he carry the clay and gravel to the top? (Under its curved abdomen.)

What use to plants is there in bringing up so much of the deeper layers of earth as the hundreds of crayfish on each acre do? (Brings up new soil and makes it easy for roots to grow down.)

What *damage* to man, when crayfish honeycomb the banks of streams, levees along large rivers, etc., with their holes? (Makes them weak, till at last they may break or cave in.)

22. Do crayfish make a *home*? (Not for a *family* to live in.)

* Huxley, pp. 79-81.

When are the eggs laid ? (In early winter.)

How many ?

What queer way of caring for them ? (They stick to the swimmerets of the mother's abdomen.) *

Look at the picture in Huxley and see the queer claws with which the young hang on to the old egg cases till they are old enough to leave the mother.

Do the young resemble the mother ? (Yes.)

23. How can the young *grow* when incased in a stiff outside skeleton ? (Shed shells.)

Yes, this is done several times the first year, and after each molt the crayfish rapidly expands while the skin is soft, and then a new shell forms. Frequently crayfish are found with one big and one little front claw.

How did it happen ? (Sometimes a claw is lost in molting or by accident, and then, wonderful to tell, *another sprouts and grows.*)

24. Are the two sides of the body alike ? Name the organs on one side in order from front to back.

Are they warm or cold blooded ?

What is the color of the blood ? (Watery.)

SNAIL (*Limnæa*).

Search ponds and ditches for some of the air-breathing pond snails, and gather enough so that each member of the class can have a couple to study. Also gather plenty of the dead shells, and it will be well to add dead shells of Planorbis or other *left-handed* shell.

Place the live ones in shallow dishes or glass jars, with some pond weeds, several weeks before the study, that the pupils may observe their habits.

Morse's First Book in Zoölogy will be very helpful in this study.

1. **Give shells** to the class.

* Huxley, pp. 40, 41.

How many parts to this snail shell ? (One.)

Its color ?

General shape ?

What is at the large end ? (Opening.)

We call this the **aperture**.

What do you notice about the other end ? (Pointed.)

Hold the pointed end (**apex**) up and the aperture toward you.

On which side is the opening ? (Right or left.)

Begin at the apex and follow the spiral crease to the bottom.

Where does it end ?

These are called the **sutures**, and the bulges between them are the **whorls**.

Do you notice any other lines ? (Across from one suture to another.)

The thin edge of the aperture is called the **lip**.

How do these cross lines run with regard to the lip ? (Parallel.)

They are called **lines of growth**.

How does the shell feel ? (Hard.)

Drop a poor one in acid. (Effervesces and dissolves.)

What are they made of ? (Carbonate of lime.)

2. **Aperture**.—Shape of opening ? Is the lip thick, or thin ?

A regular or a broken curve ? All try and find as *many* kinds of snail shells as you can, and let me see them.

3. Now give *live snails* in sauce dishes of water.

What is inside these live shells ? (Animals.)

What do we call its skeleton ? (Shell.)

Where is this skeleton ? (Outside.)

How does the animal *feel* ? (Soft and cold.)

Its color ?

Parts ? (Head, foot, breathing tube.) See Morse, p. 11.

4. **Foot.**—Where is the foot? (On the stomach.) Its shape? Motion? (Watch a snail crawl up the side of a glass jar). Use? Does it carry a little plate of shell on the back of the foot to close the aperture when in? If not, can you find such a snail? (Morse, p. 12.)

5. **Head.**—Where? (Front of foot.)

Parts? (Mouth, feelers, eyes.)

Where is the mouth? (On the underside, near the front.) Shape? Motion? (This can be seen as the snails crawl on the glass or float, foot up, on the surface of the water.)

Watch for a little white speck going in and out of the mouth. This is the *tongue*, a most wonderful thing.*

Small as it is, it has *hundreds* of beautifully formed and very hard, platelike teeth, arranged in regular order on its surface, making it a very efficient organ to file off bits of the food. As it wears out at the tip, it grows behind. Can you find snails having the mouth differently situated? †

6. **Tentacles**, or feelers. Where are they placed?

How many? Shape? Motion? Use? (To feel with, and perhaps hear.)

Can you find snails with a different number or form of tentacles?

7. **Eyes.**—Where placed? How many?

Are they simple, or compound? (Simple.)

Can you find snails with the eyes differently placed? †

8. **Where** do these snails **live**? (In ponds and still water.)

How do they move? (Glide along on the single foot.)

What do they eat? (Minute plants usually, but do not refuse animal food if found.) #

* See cuts of the lingual ribbon in Tenny, 402; Orton, 65; or other Zoölogy.

† Morse, p. 12.

‡ Morse, p. 16.

I have seen a dead hog floating in a pond literally *black*

9. **How do they breathe?** If the pupils have been watching the snails they can hardly have failed to see them rise to the surface, turn over, foot up, and with a tiny *pop!* open their breathing tube at the surface. After a moment this is closed and withdrawn into the shell, the snail turns over, and descends again to feed.

Try and find snails which never come up to breathe. These have *gills*.

10. **Eggs.**—Where laid? How many? How laid? (In jellylike cluster.)

Find how long it takes them to hatch.

Can the little snails move and feed when hatched?

Do they resemble the mother? (Yes.)

Can you find snails which lay their eggs singly?*

Which lay little *live* snails? †

11. How can the little snails grow, living in a hard shell? (Covering the body is a skin called the *mantle*, which is able to form shell, and as the snail grows it continually adds on to its shell.) Where? (At the lip.) Why are the lines parallel with the lip called **lines of growth**? (Because they show the successive additions made to the shell.)

Where does the lime for the shell come from? (Snail's food.)

Why are snails especially abundant in districts where there is much lime in the soil and water?

The Clam (Fresh-water).

Having studied the hard-shelled Venus in a previous step, I would here choose the fresh-water clam (although any bivalve will do by making the necessary changes in

with snails, and frequently seen them clustered on smaller decaying animals in the water.

* Morse, p. 20.

† Morse, Figs. 15 and 16, Paludina.

what follows). Have the boys aid in collecting enough pairs of shells so that each pupil may have one. Wash clean and tie mates together. Have a few live ones of the same species in dishes of water, with a sand or mud bottom for them to move about in. After these have been under observation for some days, begin the study.

1. **Shell outside.**—Shape as a whole? Surface? (Usually with a kind of skin or “epidermis.”) Colors?

Is the epidermis worn off at any place? (That knob is the “**beak.**”)

What else about the outside of the shell? (Lines.)

Where do these begin and end? Where smallest? (Around beak.)

How is their direction related to the edge of the shell? (Concentric.)

What did we see like them in the snail? (Lines of growth.)

Do the edges of the shell fit tightly all around? (Open cracks, high up behind and low down in front.)

Hold the shell with the beak to the left and edges down. What do you notice on the upper side? (Brownish substance.)

This is the **ligament**. Now untie your shells. (They *open* a little.) *

When the clam is alive the ligament is like India rubber.

When the shell is closed, what happens to the ligament? (Stretched.)

What is it that causes motion in our bodies? (Muscles.)

Clams have muscles also. To do which, open or close the shell? (Close.)

What opens it again? (The ligament contracts.)

How many parts to a clam shell? (Two.) Are they alike in size and shape?

* Show this with a fresh dead shell if the others are too old.

2. Shell **inside**? Surface? (Smooth and concave.)
Colors? What running around near the edge?
(Line.)

This is called the **pallial** (mantle) **line**.

What do you find at either end of this line? (Oval spots.)

Those are called **muscle impressions**, as they are where the muscles closing the shell are fastened.

Are the two halves of the shell *exactly* alike? (Note differences in the **teeth of the hinge**, just below the ligament.)

What substance are clam shells made of? (Carbonate of lime.) Put a piece in acid.

(It is a great temptation here to dissect, but I think, on the whole, the temptation is to be resisted. Nine to ten year children are not old enough to do it, and I should adhere to what can be seen and learned without it.)

3. **The Clam itself**.—Where is it? (Inside the shell.)

What parts can you ever see? (White *foot* and delicate fringe.)

Where is the foot put out? (Through the crack below the beak.)

What color is it? Hard or soft? Motion? (Out and in.)

Use? (Clam pulls itself through the mud with it.)

4. **Siphons**.—Where is the "fringe" put out? (Through the crack back of the ligament.)

When out, *very* gently drop some colored liquid (indigo or red ink) in the water near them. Can you see any movement in the water?

Which way? (*In* at lower side and *out* at upper.)

The "fringe" is the ends of the two siphons through which water is passed in and out of the clam.

Can you think what it breathes? (Air in water.)
What with? (Gills.)

Yes, you are right, and some day I hope you can see these curious gills.

5. **The Young.**—Were the smallest clams you ever saw clam-shaped?

The mother clam has a curious way of carrying her eggs in her *gills* till they hatch. Then the little ones, much *unlike* their mother, pass out with the current of water through the upper siphon and, if they can, fasten on to a *fish* till they have grown somewhat larger and become really like clams.*

In what ways are snails and clams *alike*? (*Limy shells covering soft bodies.*)

Earthworm.

Place a number of worms on some loose, moist soil in a box, and observe their way of penetrating the ground. On the surface scatter a few leaves, some blunt and some pointed, and test some of the conclusions regarding the intelligence of worms Darwin speaks of in his *Vegetable Mold* (pp. 32 and 33, and 65-91). Any one will be greatly interested in at least the first two chapters of this classic study of a remarkable animal, and in what follows my own observations have been greatly aided by his wise guidance. At least once during the lessons give each pair of pupils a couple of worms in a *wet* saucer covered with a piece of glass, as some will be afraid to handle the worms enough to keep them in the saucer.

1. **Worm.**—Shape? Color? Parts? (Many rings or joints.)

2. **Skin.**—How does it feel? Are the rings all equal? (Girdle.)

3. **Head.**—Has the worm a head end? Which is it? How distinguished from the tail? (Nearest girdle.)

* Kingsley, *Riverside Nat. His.*, vol. i, p. 270.

Where is the mouth? (On the underside of the head.)

Can other organs be seen—eyes, ears, etc.? (No.)

4. Where does the worm live? (In the earth.)

How does it make its hole? (*Eats* a hole, or penetrates by making its head very slender and inserting it in some crack and then *swelling* out and pushing the earth aside.) Which *must* it do in compact soil? (Eat.) What *can* it do in loose soil?

5. **How** does it **move**? (See backward-pointed *bristles* on underside, and note how in climbing the smooth side of a dish it hangs on with its *mouth* by sucking.)

6. **What** does it **eat**? (Earth, decaying leaves, etc.)

What does it eat *earth* for? (The minute plants, eggs, animals, etc., in it.)

Who has noticed little piles of fresh earth about the garden or walks?

These are called **worm casts**. Are there many of them?

Can you think of any benefit from all this earth brought up? (Keeps changing the soil for plants.)

How do the *many* holes and soft places where the filled-up holes were aid plants? (Make easy places for roots to penetrate.)

Suppose a lot of clam shells or bones lay on soil where worms were, what would slowly happen? (*Sink* from the earth taken from underneath and gradually be *covered up* by castings.)

How would this help? (Hide the bones, etc., place them where plants could feed on them, and level the ground.)

7. **When** do worms **feed**? (At night.)

Have they any way of preparing food for themselves? (Pull leaves into their burrows.)

Do they seem to have the power to *choose* among leaves?

Do they seem able to select the best *way* to pull a leaf in ?

Do worms seem to feel a jar to the earth ?

Do they, when out at night, notice a light ?

When alarmed by a jar or by light, what do they do ? (Quickly withdraw into burrows.)

Some day you must read Mr. Darwin's book about these wonderful animals.

The Starfish.

I have never had any but dried specimens to use, and can give no advice about the use of live ones. Provide one of some cheap variety for each pair of pupils. The main point to develop is the *radiate* structure.

1. **Parts** ? (Arms and disk.)

2. **How many arms** ? How arranged ? (Radiate.)

Upper side ? Lower side ? (Stomach extends along the grooves in the arms.)

The rows of little knobs on either side are the *tube feet*, which end in sucking disks. By these the live starfish can fasten an arm on to anything and draw itself up to it.

Has it a head and a tail ? An above and below ?

3. The **mouth** is in the center of its underside, and the starfish has a *very* peculiar way of feeding. It turns its stomach *out of its mouth* on to the food and absorbs it.

4. **Where do starfish live** ? (In the salt water of the sea.)

5. Has it an outside or inside **skeleton** ? What is it made of ? (Carbonate of lime. Test some bits in acid.)

Has it two symmetrical (like) halves ?

The Coral.

Have fragments of white coral for the pupils, and add such help as possible from pictures.

1. **Where** did these come **from** ? (Sea bottom.)

Of warm or cold seas? (See some Physical Geography—warm seas.)

Where are the coral reefs located? (In ocean and along continents.)

See if any reefs are near the mouths of rivers. (No.)

2. Examine your fragment and tell me if it is *stone*.

Why not stone? (Has regular structure.) Drop a bit in acid.

What is it made of? (Lime and CO_2 .)

What other things made of the same have we studied? (Eggshell, crayfish shell, snail and clam shells, and starfish skeleton.)

How were all these made? (They *grew* as part of some animal.)

So it is with the coral. It is the hard part, skeleton, of the coral animal, very many of which usually live together. Each little pit on your pieces was where one lived.

Are the animals in the pits now? (No.)

3. Here are some pictures of the animals as they look when alive.

Where is the mouth? (In center of upper side.)

How are the **tentacles** arranged? (In a circular fringe around it.)

Of what use are these? (To catch food.)

How do they hold the prey, being so smooth and slippery? (All along the tentacles are wonderful little **stinging cells**, which seem to paralyze the prey; the tentacles then convey the food to the mouth.)

Where does the lime come from? (The food it eats.)

As to number, are they in sixes, or eights? (Six or multiples of six.)

4. Examine the little pits where the coral animals lived.

What do you notice? (Little plates of coral.) Are all these equal?

How are these arranged? (Around the outside.)

How many are there? Is the number divisible by six, or eight? (Six.)

How does the coral resemble the starfish? (Organs arranged in a *circle*.)

We call such an arrangement *radiate*.

The Sponge.

Provide small ones, with distinct and well-formed openings at the top. Go or send to some wholesale druggist, where a lot of good specimens can be cheaply had. Read in preparation Professor Hyatt's Commercial and Other Sponges.

1. General **shape**? Color?

2. What is it composed of? (Tough, horny fibers.)

This is the **skeleton** of the sponge. When alive it looks much like a piece of liver growing on the rocks at the bottom of warm seas. These are gathered by divers or by sponge fishers with rakes and forks.*

Read to the class what Professor Hyatt tells about the gathering and preparing.

Why is one side of the sponge cut? (Where it was separated from the rock or larger sponge.)

3. Each of these liverlike masses is a whole *colony* of animals living together like the people in a city.

What in the skeleton corresponds to the streets? (Tubes.)

Yes, and these tube streets are lined with groups of little animals.

What fills these tubes in life? (Sea water.)

This is drawn in through fine, strainerlike holes—where? (Sides.)

As it passes along the tubes the minute animals and

* See illustrations in Riverside Nat. His., vol. i, or Hyatt's Science Guide, No. III.

plants it contains are seized for food by the little animals, and then the water is emptied out through a few large openings—where? (At the top.)

Now examine carefully the *bases* of your specimens, and tell me whether your specimen is a *whole* sponge, just as it came off the rock, or a cut-off *branch* of a large one. (Base of whole sponge will have few holes, and contain bits of rock or shell, while a branch will show the large tubes and no rock.)

4. What do you notice more about these skeletons? (Elastic, soak up a great deal of water, and then are soft and delicate.)

5. Show pictures of or draw on board the curious flagellate cells which seem the individuals of the sponge colony, and review the way they feed.

Have these little cell-animals any eyes, ears, etc.? (No.)

Simple as these are, there are yet simpler and lower ones, but these we can not study now, and this ends, for the present, our lessons on animals.

Review.—None desirable.

Material.—Should be sorted, replaced, and put away in boxes, so that the hand can be at once placed upon what may be wanted again.

The next step in Animals will be XXIX—Winter Quarters of Animals.

STEP XXVIII.—PLANTS.

THEIR RELATIONS TO SURROUNDINGS.

Object.—To widen and increase the pupils' acquaintance with plants.

To review, in other relations, past lessons along all lines.

To aid in geography.

To prepare for future work.

Time.—Autumn of the year. Of the day, at the close of school, when all other classes can be dismissed and more freedom be allowed.

The number of lessons will be about thirty, of fifteen to twenty minutes each.

Material.—Little or none is needed, although a wise and observing teacher will gradually gather a store of specimens to illustrate, which to the gatherer will be valuable.

Preparation of the Teacher.—Go through the lesson carefully and *test* everything possible. If this is begun in the previous *spring* and continued through the summer many valuable things will be seen and interesting discoveries made. Should the school have a garden plot, a class that has had the lessons might superintend the carrying out of many test cultures by the class that is to have the lessons in the fall. In case the school has no garden the teacher's home garden might become the center of intensely interesting work. No one fully grasps these things who has not *seen* and *worked over* them. For *books*, consult physical geographies and

physiological botanies, but the range is too wide to be found in any one book, unless it be Kerner and Oliver's "Natural History of Plants."

THE LESSONS.

These are to **draw out** what the pupil has learned through experience and observation or from the preceding lessons on minerals, plants, and animals, and exhibit *new* relations. Hence, *tell nothing* that can in any way be drawn out by question or experiment.

The steps in teaching should be as follows:

a. **Introduce** the point to be considered in such a way as to have it clearly before the class.

b. **Find** what **ideas** the class may already have.

c. If there are other relations which they have not thought of, **suggest** them by illustration, experiment, and question.

d. Let all conclusions go on the board or into notebooks, and at the close sum up all about the point in hand.

e. Promptly pass to the next, and have the progress steady. More interest is killed by a dilatory manner of handling the subject than in any other way known to me. Very dry subjects become attractive through *vigorous handling*. Hence, do not begin till you are ready to push the matter to a close, and then as promptly stop.

1. **Sunlight**.—What do plants get from the sun? (Light and heat.)

How does light affect them?*

Some open. (Tulip, poppy, and water lily.) Find others, and tell us.

Some close. (Morning-glory, four-o'clock, and evening primrose.) What others?

* Let the class think of the morning and other times of day, and tell what they can of all the things that the sun will do to the plants, and illustrate by examples.

Plants turn toward the light. (Lupine leaves and all window plants.)

Leaves turn green. (This is apt to be all the class will think of.) Now suggest, Who knows the oxalis or white clover? See how the leaflets are arranged to-night, and again to-morrow morning. (They *wake up!*)

Do all leaves "sleep"?

Smell of squash, mignonette, four-o'clock, and other flowers to-night, and again to-morrow before coming to school. Is there any difference in the odor? (Squash and —? were *stronger* in the morning.)

There is another and *very* important thing which sunshine makes leaves do. Here are several fruit jars, with good rubbers to close them securely. In each I will pour two cm. of water. Here are several bits of candle on wires. John, Kate, Mary, and Sam may come and help me light the candles and hold them in the jars *till they go out*.

What have the burning candles made in the jars? (CO₂.)

If I light them again and lower into this CO₂? (Will go out.)

We will try it and see. Yes, they *do* go out.

Now, in each jar I will stand these sprigs of mint (or other plant which will keep fresh in water) and screw on the tops *tightly* and set in the sun for two or three days.

What will the growing leaves do? (Eat up the CO₂.) We will see.

Where must I have the leaves? (In the sunshine.) How can I prove sunshine is needed? (Put one in the dark.)

We will do this, and at the end of the time how can we test? (Try the candles again.)

While waiting let us try another experiment. Here are sprigs of the same plants in the fruit jars. I will fill

these tumblers with cistern water, push a leafy sprig into each, and invert them in these saucers and set in the bright sun. What happens? (Bubbles of gas come off.)* Move into the shade? (Gas stops.)

What is it that sunshine makes green leaves do? (Purify the air by removing the CO_2 .) Yes, and what besides taking in the CO_2 ? (Give out gas.) If we could test this gas which is given off we should find it to be *oxygen*, just what we need to breathe. Where does the plant get it? (From the CO_2 .)

Review Sunlight. In this manner take up the following points:

2. **Darkness.**—How does this affect plants?

Some open. (Four-o'clock, evening primrose.)

Some close. (Marigold, daisy, crocus, tulip.)

Leaves sleep. (Oxalis, lupine, white clover.)

Some odors are strongest. (Four-o'clock, night-blooming cereus.)

CO_2 is not taken in. (Test jar in the dark. See 1.)

Oxygen is not given off. (See 1.)

3. **Heat.**—How does this affect plants?

Causes rapid growth.

Water passes off from the leaves.

Kills if too great.

4. **Cold.**—Checks growth.

Some leaves fold to keep warm. (Seed leaves of radish, morning-glory, four-o'clock.)

Leaves fall. (All deciduous trees, etc.)

Buds put on thick scales. (Hickory, ash.)

Tender plants die. (All in temperate zone.)

Hard seed pods or husks are opened. (Hickory nuts, black walnuts.) (See Sharp Stones, Step XX.)

Prepares and loosens the soil. (See Sharp Stones.)

* See Goodale's *Physiological Botany*, p. 305, for suggestions about this experiment.

5. **Air.**—Supplies the CO_2 . (See Morning-Glory, Step XXIII.)

Receives oxygen from the leaves. (See 1.)

Receives water from the leaves. (See Morning-Glory.)

6. **Wind.**—Carries pollen. (Grasses, pines.) What others ?

Carries odors. (Rose, heliotrope.)

Scatters seeds. (Maple, dandelion, cottonwood.)

Changes the air.

Injures by drying too much.*

7. **Dew.**—Moistens the leaves and ground. (Benefits by diminishing evaporation from the leaves and by condensation in the pores of loose, dry soil, thus greatly helping in dry times.)

Which leaves have the most, those held horizontally, or those held edgewise or vertically ? (See oxalis, white clover.)

Which the most—hairy or smooth leaves ? Why ?

Which part of the leaf has the most ? (Tip.)

Is the dew on the upper or on the under side ? Why ?

Does it form under the shade of trees and bushy plants ? (Why not ?)

8. **Rain.**—Supplies moisture to the roots.

Moistens the surface (like dew).

Washes off dust, etc.

Softens the bud scales so that they open easily.

Softens the soil for roots to penetrate and seedlings to emerge.

* Dry winds often so injure the stigmas or pollen grains of flowers just ready for fertilization as to cause a "short crop" of grain, cherries, etc. On the other hand, a very still time, when corn is in bloom, prevents the stirring of the silk, and the falling pollen fails to reach the long styles and stigmas in the center, so that there is a long "tip" of undeveloped ovules at the end of the ear.

Wastes pollen and nectar.

How do the following plants avoid this waste ?

Portulaca and common purslane ? Petunia ? Honey-suckle ? Daisy or dandelion ? Sunflower or oxeye daisy ?

(Some of these do not open, others are drooping bells, others have fine tubes into which the drops can not get because of the imprisoned air.)

Forests increase the rainfall.

9. **Drought.**—How do plants manage in a very *dry* time ?

The roots strike downward. (Illustrates the need of *deep* plowing and digging.)

Leaves droop and curl, so as to protect themselves. (Cornfields, etc.)

Leaves *fall* off to prevent stem being exhausted.

Where it is always dry ? (Cacti.) Leaves are reduced to little brown spines, and the green stem takes their place.

Deserts ? (So dry nothing can grow. Prevent the spread of plants.)

10. **Brooks and Rivers.**—What have these to do with plants ?

Rub rocks to pieces and make soil. (See Sharp Stones.)

Make rich river bottoms and deltas. (Show Nile, Mississippi, and Ganges on map.)

Water rainless tracts. (Nile and western United States; see map.)

Transport seeds and plants.*

Are kept at even flow. (See 11.)

11. **Soil.**—What kinds can you think of ? (Rich, sandy, rocky, etc.)

How do plants thrive in fertile soil ?

1. Grow rank and large. (Rich garden.)

* Natural History of Plants, ii, p. 846 ff.

2. Are late in blooming and fruiting. (Vegetables or grain on very rich soil are apt to be cut by frost before maturing.)

How on sandy soil? (Dwarfed; bloom and fruit early but sparingly.)

(Gardeners who want early tomatoes, melons, or corn, are careful not to have the soil very rich.)

How do plants affect soils?

Keep loose sands from drifting. (Beach grass and mangrove.)

Strengthen the banks of rivers. (Willows, alders, etc.)

Break rocks. (See Step XX.)

Make the soil black. (Decay of leaves, etc.)

Exhaust the fertility. (Tobacco lands of Virginia, etc., and "worn-out" lands everywhere.) An interesting experiment is to weigh a dry cigar or other dry leaves and then burn in a clean open dish and find the per cent of ash by weighing. This gives some idea of the enormous drain tobacco and other leaf crops are to the soil.

Enable the soil to hold much water. (The spongelike mass of decayed leaves in a forest holds immense quantities of water, and after a rain permits it to gradually drain away, thus preventing the floods which rivers in unwooded countries are subject to, and keeping the springs and streams at a steady flow; see 10.)

12. **Gravitation.**—How does this affect plants?

Causes roots to strike downward.

Causes seeds to fall where they can grow.

13. **Mountains.**—Have they any effect on plants?

Prevent the spread of plants.

Shelter those in the valleys.

Raise those on top into a higher, drier, and colder climate.

Show the class some physical geography chart, or represent it on the board, showing the effect of mountains

in a tropical climate. Note the kind of plants (palms, tree ferns, etc.) at the base; next the hard-wooded trees and grains of the temperate middle section; then the cone-bearing trees, etc., of the next belt, gradually dwarfing and giving way to low willows, and at last mosses and lichens, which end in everlasting snow.

14. **Latitude.**—What is “latitude”? (See Step XXII.)

Where does the sun shine perpendicularly? What zone do we call it?

What is the effect on the plants that live there? (Rank and large.)

Where are the nights longest? What is this region named?

How do plants thrive with so little sun? (Dwarfed or none.)

Why is the middle section called the “temperate zone”?

How about the plants where warm and cold seasons alternate?

What does the gradation from the huge and rank plants of the tropics to the barrenness of the arctic zone remind you of? (Mountain-sides.)

15. **Time.**—How does length of life affect a plant?

Those with soft tissues, dying down each year, we call? (Herbs.)

Those with woody tissues? (Shrubs or trees.)

Those living one year are called? (Annuals.) Name some. (Beans, etc.)

Those living two years? (Biennials.) Name some. (Carrot, etc.)

Those living several years? (Perennials.) Name some. (Oak, etc.)

What does the continued growth of perennials give us? (Size and beauty of trees and shrubs and wood for building, fires, etc.)

16. **The Sea.**—How does this affect plants ?

Nourishes some. (Seaweeds.)

Destroys land plants by its salt water.

Carries some seeds and fruits to new islands and lands.*

What fruits do you know of seemingly able to stand sea water ? (Cocoanut, date, breadfruit.)

Is the unfrozen ocean as cold as the land in winter ? (No.)

As warm in summer ?

What way is there for this heat or coolness to be carried to the land ? (Winds.)

Suppose these blow *off shore* ?

How if they blow landward most of the time ? †

How will oceans affect the plants near which they are ?

How about the climate of islands ? (Milder and even.)

17. **Other Plants.**—Will plants growing near together **help**, or **hinder**, each other ?

What do plants take from the soil ? (Earth food.) (See Morning-Glory.)

Will it help, or hinder, for others to grow in the same soil ?

How many reasons can you think of why *weeds* are injurious ? (First, look badly ; second, drain the water

* Wallace, *Island Life*, pp. 257-259.

† Show the class charts or maps of the distribution of heat or vegetation, and lead them to observe the greater warmth and consequent extension toward the poles on the *western* sides ; the downward curve in the center of great land masses and the intermediate condition on the eastern shores, where the winds from the ocean are less persistent and do not affect the climate far within the interior. Illustrate this fully on charts and globes, and the "seed thoughts" planted in this connection will develop into a clear comprehension of this important subject.

from the soil; third, exhaust the needed "earth food"; fourth, shade the plants we want, and prevent the sun doing its work.)

Why do farmers find it best not to plant the same crop on a piece of land for a number of successive years? (See 11, Soil.)

How does the dandelion make room for itself in the grass?

How would the morning-glory interfere with currant bushes?

Why does the broad-leaved and quick-growing buckwheat "kill the weeds"?

Why does a field of "timothy" grass so soon "run out" and become redtop?

Fayal, an island in the Azores, was named from a small tree called the Faya, which grew abundantly and supplied excellent fuel. Some one brought to the island another small tree, the Pittosporum, for the sake of its beautiful, glossy leaves and clusters of fragrant white flowers, followed by orange-colored pulpy fruits. This has very poor wood for fuel, and yet it is *spreading everywhere* and driving out the better Faya. Why? (Birds scatter the indigestible seed.)

The sheep sorrel (*Rumex*), which reddens so many pastures; the bitter oxeye daisies, which dot the meadows; the plantain ("white-man's-foot") of our lawns; and the mayweed by the roadside, are other examples of this struggle for life.

On the other hand, let some of the pupils cut a square foot of turf from a pasture with a close sward, and others similar areas from a grain field or cultivated meadow where *one* kind of plant alone grows. Shake the earth from these, and find in each case:

1. How many *plants* to the square foot.
2. How many *kinds* in each case.

From these counts (placed in tabular form on the

board) the class will almost invariably discover that *different* kinds of plants get along better together than many of *one* kind. Why do we sow a mixture of several grasses and clover if we want a thick, green lawn?

Why do farmers say, "The worst weed in a cornfield is *corn*"? The same might be said of any crop which stands too thick.

How do plants manage to spread their area of growth?

The balsam, tame or wild? (Snaps.)

The dandelion? (Wind carries.)

The burdock? (By its hooks.)

The pea or bean? (Carried for food.)

The raspberry? The strawberry? (Two ways: eaten by birds and spread by "runners," etc.)

The apple? (Eaten by animals.)

The chestnut or other nut? (Eaten by squirrels, etc.)

Corn or other grain? (Eaten by man, squirrels, and mice.)

The class can now readily see the *use* to the plant of its edible, colored, fragrant, hooked, plumed, winged, and snapping fruits and seeds. Also why many seeds are so hard and indigestible. To sum up this point:

Plants are continually struggling with each other for food, etc.

Those of the same kind make worse neighbors than those that use different elements of the soil for food.

Plants secure a scattering of their seed by aid of their colored fruits, hard seed, wings, hooks, etc.

Plants also **help** each other.

How does a tree help a vine?

How do the different corn plants in a field aid each other? (Pollen.)

Half of the willow "pussies" have no stamens. How do they get pollen? (From another bush.)

What will be the result of a stalk of red corn growing among yellow corn? (The yellow ears will have red

kernels scattered on the ears, or have striped "calico" ears of corn. We call this "crossing.")

Can you find evidences of crossing in other flowers, fruits, or seed?

18. **Insects.***—Think of all the ways you can in which plants and insects affect each other. First, **How do plants affect insects** by

Odors? (Attract.) When are odors usually strongest? (See Step XVII.)

Colors? (Attract.) What color is most common among night bloomers? (White.) Why?

Shape? (Guides and prevents the nectar being taken without the pollen being carried.) (See Morning-Glory.)

Separation of stamens and pistils, making insects carry the pollen from one flower to the stigmas of another.

Nectar? (Rewards the visiting insects.)

All this is friendly and mutually helpful. Against injurious insects or those not helpful, we find †

Hairs. (Place ants or small beetles on hairy plants, and observe.)

Sticky secretions. (Place small insects on tomatoes, petunia, or Pentstemon.)

Color. (Dull yellows are mostly avoided by beetles, but visited by the helpful flies, bees, and butterflies.) †

Offensive odors. (Mint, geranium, musk plant, etc.) Are such plants eaten by many insects?

Strong taste. (Observe sweet fern, sorrel, rhubarb, and green fruits.)

Hard, woody leaves. (Do caterpillars like young, or old, leaves best?)

* Natural History of Plants, ii, p. 152 ff.

† Natural History of Plants, ii, p. 231 ff.

‡ See Goodale, p. 455, or Coulter's Plant Relations, p. 136.

Structure of flowers :

1. Throat *closed*, and opening only with the weight of a heavy insect. (Snapdragon, etc.)

2. Throat a *narrow tube*, where only insects with long tongues can reach the nectar. (Red clover, etc.)

3. Throat filled by the stamens and pistils. (Phlox and petunia.)

Second, **How do insects affect plants?**

Carry pollen, and so cause seed to grow.

Cross fertilize, the pollen of one plant being carried to others of the same kind. (Squash, willows, orchids, etc.) This gives—

1. Stronger plants. (Morning-glory, as 85.84 is to 66.02 inches.)*

2. More seed. (Morning-glory, as 100 is to 51.)*

3. New varieties. (Mixed corn, morning-glories, etc.)

Eat them. (Grasshoppers, potato beetles, rose beetles, etc.)

Lay eggs on them, causing—

1. Galls. (Oak "apples," golden-rod gall, rose galls.)

2. Boring larvæ. (Currant, raspberry, and apple-tree borers.)

3. Sucking insects. (Plant lice and squash bugs.)

4. Eating larvæ. (Caterpillars of tomato and Virginia creeper, and slugs of cherry and rose.)

(Cutworms, which eat young plants off at the ground.)

Destroy injurious insects. (Ichneumon and lady beetle.)

19. **Birds.—Plants help** the birds by—

1. Food. (Class tell of different foods and what birds eat them.)

2. Shelter. (Where and when ?)

* See Darwin's experiments; and Goodale's *Physiological Botany*, p. 448.

3. Screens for their nests. (Expand this.)

4. Material to build nests. (What are these materials?)

5. By purifying the air from CO_2 and restoring the oxygen.

Birds repay the plants by—

1. Carrying seeds to new places.* *Pittosporum* in the Azores (17).

How do "thimble berries" (black raspberries) come to be so common by fences and walls? My garden has much knotweed, with hard, shiny black seeds. Why do patches of it keep coming up in the grass of my front lawn? (Hens.)

Pigeons swallow acorns and other large fruits whole, and then feed their young by raising the softened food from the crops and placing it in their mouths. How might seeds and fruits be easily started in new places? Mistletoe.† See account of the spread of the nutmeg in the Spice Islands.‡

2. Eating injurious insects. Each part of the tree and each place, high or low, has its particular set of birds to attend to this: as

In the ground. (Scratching hen, etc.)

On the ground. (Hen, brown thrush, robin, duck, etc.)

On bark. (Nuthatch, brown creeper, etc.)

Under bark. (Woodpeckers.)

Leaves and buds. (Warblers, etc.)

Flowers. (Humming birds.)

Fruits. (Blue jay, woodpecker, cherry bird, robin.)

In the air. (Swift, swallow, and pewee.)

3. By food. CO_2 is constantly given off.

* Wallace, *Island Life*, chap. v.

† *Nat. Hist. of Botany*, i, p. 205 ff.

‡ Wallace, *Malay Archi.*, pp. 288 and 418.

The guano beds off Peru are vast deposits of the droppings of sea fowl.

Hen manure is also very rich food for plants.

20. **Animals.**—How do plants help these ?

1. By food. What is eaten ? By what animals ?

2. By shelter. (When, where, and how ?) Storm and winter. Hollow trees, under branches, etc.

3. By floating them to new places. .

Trees are frequently torn away from the banks of a river by freshets. What might happen to insects or borers on them ?

Suppose a sudden flood should sweep a nest of squirrels or a snake away on the log ?

4. By purifying the air from CO_2 and restoring its oxygen.

How do animals help plants ?

1. They carry seeds to new places.

Burrs, etc., on sheep or in the tails of animals.

Indigestible seeds.

Grain and nuts. (By mice, chipmunks, and squirrels.)

2. Animal waste is *food* for plants.

CO_2 is constantly given off. What part of the plants takes it in ?

Compost from stables is so valuable for crops as to be constantly employed.

“Bone dust” is the ground-up bones of dead animals.

“Blood-and-bone” fertilizer. Its name indicates its origin in the refuse of slaughterhouses. (Fine for crops.)

“Superphosphate” is prepared from animal remains. That from South Carolina is the remains of extinct animals.

Bones and other remains of animals buried where the roots of grapevines or other plants can reach them soon become covered with a net of feeding roots.

The niter deposits and “bat earth” of Mammoth and

other caves are rich in plant foods and formed from the droppings of the multitude of bats that swarm in them.

Guano is obtained from rainless islands (Chincha, Lobos, etc.), which have been the roosting places of sea birds for many years.

The menhaden and other abundant fish have long been caught to make an artificial guano. The oil—of no value to plants—is first expressed and the remaining bones, skins, etc., ground up.

How do plants defend themselves against animals?

1. Roots and tubers are buried in the ground. (Give examples.)

2. Many stems and leaves become too woody and dry to be agreeable food.

3. Some arm themselves with spines or thorns. (Wild apple, Osage orange, rose, and especially the much-exposed cacti, etc., of deserts.)

4. Many leaves are *pungent* (mints, geranium, etc.); *bitter* (oxeye daisies and bulbous buttercup make cows sick); *sour* (animals avoid sheep sorrel—*Rumex*—and rhubarb); *wooly* (mullein is seldom eaten); *prickly* (thistles in all their variety); *poisonous* (castor bean, oleander); or *stinging* (nettle).

5. Flowers. Besides the devices above referred to, flowers at times hide themselves under the leaves, as in several of the violets, where the showy flowers of spring are succeeded by many greenish flowers near the roots which produce seed all summer.

6. Fruits defend themselves while growing by being—

Sour. (Apples, peaches, etc.)

Bitter. (Persimmon and black walnut.)

Hard-shelled. (Hickory nut and pecan.)

Prickly. (Chestnut burr, wild gooseberry.)

Hidden. (Many fruits bend down close to the ground soon after setting—white clover, peanut.)

Green and leaflike in color, the attractive coloring only appearing when the seeds are ripe enough to be spread.

This must close this interesting subject.

Much more might be added, but I have chosen samples of the more interesting and familiar points.

Review.—None is needed beyond that arranged for in the succeeding steps, and the constant application of all to the geography and reading lessons.

Prepare for the next step in Plants by arranging with this class to provide supplies. Plan and assign each his part, and keep a record as a reminder next spring.

The next piece of botanical work is Step XXXIV—Plants in Winter Quarters.

STEP XXIX.—ANIMALS.

IN WINTER QUARTERS.

The object of this step is to extend the acquaintance with native animals through a study of their winter conditions, and thus introduce ideas of the "struggle for life" due to environments.

Time.—In late autumn, when animal life has nearly disappeared, the studies of plant relationships will have preceded and prepared the way.

About twenty lessons of half an hour each will be sufficient.

Material.—Previous work will have made ready for this step, and it only remains to show such specimens, pictures, skins, or stuffed animals as shall make the concepts of the children clear and correct.

Preparation of the Teacher.—The literature of this subject is so scattered and fragmentary as to render references of little value to the average teacher. State and Government reports on zoölogy are frequently very helpful, while personal observation is especially so, and should be made the substantial basis of the work.

What follows is for the Central United States. Teachers in other localities, especially North or South, must vary the details to make it truthful for local conditions. Having reviewed the step, decided on substitutes (if need be) for animals here named, and in some way become familiar with the food and habits of those selected, write out such a set of notes as it is expected the pupils will keep.

The Lessons.—Each pupil should have a notebook kept especially for science work, $6 \times 3\frac{1}{2}$ inches in size, opening at the *end* and having fifty pages of *good* paper.

Use both sides of the page, but do not crowd the notes.

It is best to use a page for each animal.

Introduce the subject by calling attention to the disappearance of animals, birds, and insects which were so abundant, and raise the questions, Where have they gone? Why?

To answer these questions and open up a delightful subject proceed as follows:

First. Let each take his notebook, and, having written the title of the lessons in ink on the cover, proceed to make a list of all the wild animals he knows of in his section of the country. Encourage some attempt at classification by advising each child to put in classes the names of animals which seem to resemble each other, and, having named all he can think of, leave a few blank lines in order that additions may be made.

When the class seems to have exhausted its resources as individuals, make a count and see who has thought of the *most* names.

Second (probably the next lesson). Begin to compare notes, that each may have the aid of the others. Let pupil No. 1 read the name first in his list. If it is that of a wild animal and to the purpose, advise all who do not have it to add the name to their list of the same kind. (If of a domesticated animal, throw it out.)

Then let pupil No. 2 read his first unread name, and so continue till the lists are exhausted.

Questions regarding grouping will come up for discussion, but this is not the place to teach classification beyond the valuable step each one will take who, deciding on some characteristic, *attempts* to group his animals under it. The teacher should encourage each to

state his ideas, but not attempt to have others follow unless they choose so to do.

Now let the teacher add any desirable names which may have escaped the class.

Third, What do these animals need in order to live?

Discuss this with the class until you have developed the ideas of—

1. Food (including air and water).
2. Protection (against rain, cold, and enemies).

Should either of these (1 and 2) fail, what must the animal do ?

Again discuss this till the class has suggested

1. Must seek it elsewhere (migrate).
2. Prepare beforehand.
3. Change its mode of life (hibernate, etc.).

Illustrate these by homely examples. The first, by children gathering berries or nuts ; sheep in a bare pasture ; bee on a clover head, etc. The second, by wood and coal stored for winter, fruit preserved, hay in the barn, etc. The third, by the expedients of campers, lost persons, or travelers, etc. Having thus presented the problem and got it before the class in a clear and interesting way, proceed to apply it to the various animals decided upon, beginning with one that is well known.

Fourth. Let us now see how the animals of our lists manage when winter comes.

Rabbit.—What does it eat ? (Herbage, bark, and grain.)

How is it protected ? (Warm fur and burrow.)

What will it do in winter ? (Only change its food a little.)

Raccoon.*—Eats eggs, crayfish, insects, fruits, green corn, birds, etc.

How does he spend the winter ? Gets very fat on the

* Riverside Nat. Hist., vol. v, p. 357 ff.

abundant food of summer and fall, and on the approach of cold weather goes into a hollow tree or burrow and hibernates till spring.

Of what use is the fat to him? (Keeps him warm and supplies the needs of the body.)

Skunk.—Eats insects, eggs, young birds, mice, frogs, etc.

Can this food be had in the winter? (No.)

How does the skunk manage? (Much as the coon, hibernating in holes, where numbers huddle together for warmth.)

Squirrel.—Eats nuts and acorns. Gathers stores of these and hides them in the leaves, hollow trees, and holes. Is warmly clad in fur, and has its nest in hollow trees.

How will he spend the winter? (Half-active in holes.)

Gray Gopher.—Eats grain, young birds, mice, etc. Burrows along in the ground much like the mole. Hibernates in stacks and dry burrows.

Striped Gopher.—Eats seeds, mice, young birds, etc. Unable to procure these, hibernates in dry holes.

Chipmunk.—Eats nuts and grain, which are carried to its burrow in its cheek pouches. Lays up stores for winter, and, closing the entrance to its hole, lives through the winter in a half-hibernating state.

Muskrat.—Lives on aquatic vegetation and roots, with sometimes a river mussel, which it carries from the bottom of the water to some log or stone to open. Can such food be found in the winter? (Yes.) What trouble will the rat have? (Ice will hinder his getting at it.) How does he manage? (Burrows up into high banks from *below* the water line, or in ponds with flat banks, cuts down the rushes and water plants and piles them up like a high haycock, and then burrows up into these, forming a chamber above the water to live and breathe

in. Through these protected passageways it can always get at its food.)

Woodchuck.—Eats herbage, buds, and grain. This food can not be had in the winter, and the animal hibernates in its holes.

Mole.—Lives on worms, grubs, etc., which it burrows after through the loose earth. Can these be found in winter? (Yes, but deeper, and the mole is active all the year.)

Mink.—Eats frogs, snakes, crayfish, snails, fish, rats, mice, rabbits, and birds, if it can get them. This food can be had in winter, and the mink remains and is active.

Bat (Red or Black).—Lives on insects caught on the wing. Are insects flying about in the winter? (No.) Bats cluster in caves or hollow trees, and hibernate. (See some account of Mammoth Cave and saltpeter dirt.)

Robin.—Worms and fruit. No protection or food in winter, and hence must go (migrate) to localities where food is found.

Warbler.—Small insects eaten. Migrates.

Swallow.—Eats small insects caught on the wing. As the weather becomes cool these insects hide in grass, under banks, etc., or perish. What will the swallow do? (Fly to warmer climate.)

Butcher Bird.—Eats insects, small birds, mice, etc. Migrates.

English Sparrow.—Seeds and insects. Stays and is active.

Snowbird.—Eats seeds. Warm feathers. Stays and is active.

Cow Blackbird.—Eats insects. Migrates.

Meadow Lark.—Eats larvæ and insects. Migrates.

Blue Jay.—Eats grubs in hazelnuts and acorns, fruits, and perhaps grain. Is warmly clothed in feathers, and many remain all winter and are active.

Crow.—Feeds on grain, carrion, and almost anything edible. Warmly clad. Many remain during the winter.

Humming Bird.—Nectar and small insects from flowers. Migrates.

Kingfisher.—Small fish. Water freezes, and so must migrate.

Woodpecker.—Grubs from dead trees and fruits. May remain during winter, in active life.

Owl.—Small birds and animals. May remain, protected in its holes in trees.

Hawk.—Small birds and animals. Not well protected against cold, and food scarce ; hence mostly migrate.

Quail.—Eats grain. Burrows in the snow under grass or bushes for protection, and remains active.

Prairie Chicken.—Eats grain, and seeks protection in thick grass or in snow banks. Remains active.

Snipe.—Eats worms found in the mud. Must migrate.

Goose.—Feeds on grain. Migrates to find open water.

Duck.—Feeds on grain, water plants, and animals. Migrates to open water.

Turtle.—Feeds on insects and water animals. Buries itself in the mud at the bottom of ponds in the fall, and remains in a torpid condition till early spring.

Snake.—Eats insects, frogs, and small animals. Hibernates in holes or in the mud of ponds.

Frog.—Eats insects. Buries itself in the mud of ponds, and is torpid till early spring.

Perch.—Eats insects and other fish. Active in the water under the ice.

Honeybee.—Eats nectar of flowers. Lays up store during the summer. Through the winter the bees cluster together over the combs in the hive, thus keeping themselves and the honey warm.

Bumblebee.—Lives on the nectar of flowers. No stores are laid up. Most of the bees die, but a few queens hibernate under bark, moss, or grass.

Hornets.—Catch insects for food, although they also feed on nectar and juice of fruits. Their paper nests are deserted in the fall, and only a few queens survive by hibernating, much as the bumblebee.

Ants.—Eat almost *anything*—sugar, nectar (if they can get it), dead insects, etc. Pass the winter in their “hills” in a torpid condition.

Butterfly.—Caterpillar eats leaves and the insect eats nectar. Most butterflies die, but the caterpillars enter the pupa state in the fall, and so remain till spring.

Moth.—Caterpillars eat leaves and the insect eats nectar. Most die after laying their eggs, but the caterpillars spin cocoons of silk in which to pass the winter in pupa state, or (as hawk moths) burrow into the ground and enter pupa state.

Fly.—Eats liquid food. Hibernates in cracks or as pupæ.

Mosquito.—Blood of animals. The pupa passes the winter in the water of ponds.

Plant Beetle.—Lives on herbage. Beetles die after laying eggs, and the young pass the winter as pupæ in the ground.

Squash Bug.—Lives on the juices of the squash vine. The bugs hibernate under rubbish or in crevices.

Aphis.—Feeds on the juices of plants. Most perish in the fall, the eggs surviving to produce new colonies in the spring. (See Comstock's *Insects*, pp. 158 and 637; or Harris, pp. 237-240.)

Grasshopper.—Eats herbage. Perishes when food is gone, the eggs laid in the ground surviving.

Libellula (dragon fly).—Lives on insects caught on the wing. The larvæ and pupæ pass the winter as active water animals. Some may migrate.

Spider.—Lives on the juices of insects. Passes the winter by hibernating in nests of web made in cracks, etc., or in the egg state.

Crayfish.—Eats decaying or live fish, etc., of ponds and streams. Passes the winter as an active water animal.

Land Snail.—Eats herbage. Closes the mouth of the shell and hibernates.

Pond Snail.—Eats herbage of aquatic plants in the water, and is active below the ice.

Clam.—Lives on small animals in the water, and in winter goes into deeper water.

Earthworm.—Burrows in the earth and lives upon the decaying or other material it contains. In winter (or *dry* weather), when the ground becomes hard, worms descend into deep burrows and hibernate in a closely coiled knot.

Review.—None advised. Examine the notes made by the pupils, and commend the neat and orderly ones.

Next step in Animal lessons is XXXII—Man and his Surroundings.

STEP XXX.—GRAVITATION HOLDS THE SOLAR SYSTEM TOGETHER.

The object of this step is to enlarge the pupil's conception of the earth and planets, to take up certain points in physics, gravitation, etc., which do not naturally fall in with the work of Step XXXI.

Time needed.—About twenty lessons of twenty minutes each, and by choice in the early winter, and either before or after Step XXXI—Molecules.

Material.—The most needful—in addition to the globes, etc., of the previous steps—will be a large magnet and knitting needle, a spring balance, and glass fish globe.

Preparation of the Teacher.—Read thoughtfully the parts of Lockyer's Elements of Astronomy (American edition), which are found under Chapter XVI, page 272, or the subject of gravitation in any good work on physics. Then go through this step and test the experiments, etc., modifying where necessary.

It is to be remembered that these lessons are planned on the supposition that the pupils have had the previous step (XXIV).

THE LESSONS.

The connection can be made by the following review questions:

What motions has our earth? (On its axis and about the sun.)

What other moving bodies have we studied? (Planets, comets, and moons.)

How is the motion discovered? (By watching.)

Which way do all the planets "wander"? (They seem to the observer to "wander" opposite to the motion of the hands of a watch, but with some retrograde movements and some sidewise deviations from a straight course. It is this irregularity that procured for them the name of "wanderers.")

Around what? (The sun.)

In what *plane*? (Nearly that of the ecliptic.)

In what constellations do they then always appear? (Zodiacal.)

Are their orbits interior, or exterior, to the earth's? (Both.)

Which will only appear as morning and evening stars? (Interior.)

Which will have *phases* like the moon? (Interior.)
Why?

Which can be seen at midnight? (Exterior.)

Name the interior planets.

Name the exterior.

How many large planets has the sun in his "family"? (Eight.)

How large is the earth compared with the sun? (Illustrate as follows.)

If the sun were a 12-inch globe, what would represent—

Mercury? (1 mm. pin head.)

Venus? ($2\frac{1}{2}$ mm. pin head.)

Earth? (3 mm. pin head.)

Mars? (2 mm. pin head.)

Jupiter? (30 mm. ball.)

Saturn? (24 mm. ball.)

Uranus? (11 mm. marble.)

Neptune? (13 mm. marble.)

How far is the earth from the sun? (About 93,000,000 miles.)

How shall we place our pins and balls to show the relative distances of the other planets ?

Do the interior planets have longer, or shorter, years than ours ?

How about the "years" of Neptune ? (One hundred and sixty-five years of ours.)

Why is it best for us to have short days and nights ? (Frequent *rest*.)

Why to our advantage to have short and frequently recurring *seasons* ? (Change, and we learn by *experience* how to meet them.)

Which planets have *moons* ? (All the exterior, and the earth.)

How many moons has each ? (1, 2, 5, 8, 4, 1. See Step XXIV.)

What did we learn from Jupiter's moons ? (Speed of light.)

What strange members of our "family" do we at times see ? (Comets.)

Name the star groups through which the sun seems to pass, beginning with April. (The Ram, the Bull, etc.)

Inertia.—Let us think of a few common things before we consider the next subject.

How long will this globe (or anything) remain quietly on my desk ? (Till something makes it move.)

Can anything not *alive* set itself in motion ? (No.)

A baseball is "pitched." What ways are there of stopping it ? (Bat, caught, or strikes something.)

What can it "strike" ? (Air, ground, etc.)

Suppose it did neither of these—had *nothing* to strike ? (*Never stop*.)

Be quite sure of these things, and then you can answer the next question.

Have *dead* things, like stones, balls, or even *planets* any control over their own motions ? (No.)

If at *rest* ? (Will stay so till made to move.)

If they are in *motion*? (Will keep going till stopped.)

Which *way* will they "keep going" if there is nothing to hit against? (*Straight on* the course in which they started.) This inability to change itself is called inertia.

But *do* the moons and planets move "*straight on*"? (No, in *circles*, or *ellipses*.)

Let us see if we can find out why in curves and not straight on.

If I throw a ball, what must it push aside to go on? (Air.)

Will this stop it somewhat? (Yes.)

Will it go quite as far? (No.)

If I throw the ball *up*, does it stop after a time?

Do you think it is the *air* that stops it so quickly?

Why not the air? (Does not go as far as if thrown the usual way.)

Gravitation.—Suppose for a moment it *was* only the air, what would happen when the ball came to rest? (Stay there.)

Yes, for the ball has no power to set itself going, and certainly the air which *stopped* it would not; so you would have to get a ladder or pole with a hook to pull *down* the ball every time it went *up* in tennis or baseball.

But we are not forced to this inconvenience, for what happens? (The ball *falls*.)

Is it alone *balls* that fall? (*Everything* that has no support.)

"Everything" is a *very* broad word, and includes a great many things. Let us name a number of examples and see if we need to say "most" or "nearly" before it. (No, as far as we can observe, there are no real exceptions to the rule that everything falls.)

Which *way* do things fall? (Down.)

Yes, and "down" with us is always *straight* toward the center of the earth. How about the Chinese?

We call the force which draws all things as close as possible to the center of the earth *gravitation*. I will place this large magnet on one side of the room and hang this magnetized knitting needle before you on the other side. Now it is still. I bring the magnet *slowly* across the room toward it. See! Even at quite a distance the needle begins to move. Can you *see* anything reaching out from the magnet to the needle? (No.)

The *nearer* I bring the magnet the more strongly it seems to draw the needle.

Just as wonderfully and as unseen does the earth reach out and pull everything to itself.

How does the *nearness* of the magnet affect the needle? (The nearer, the more powerful.)

Cavendish's experiment is interesting and helpful here. He took two huge balls of lead and put them on a kind of turntable (see Lockyer, p. 284); then by a fine wire or thread he suspended a rod ending in two small balls of lead. The rod was of such length as to bring the little balls just opposite the centers of the larger.

When the rod was perfectly still, the large balls were carefully brought near the small ones, and at the same time careful watch was made to see if the large balls pulled (attracted) the small ones toward them.

This was tried on both sides, and in *every* case the small balls were seen to move a little *toward* the big ones.

Does lead attract lead? (Yes.)

A *balance* or scale for weighing things is used to measure this pull of the earth on various things. Do you know of anything which has no weight?

The more there is of butter, sugar, shot, etc.—? (The more it *weighs*.)

Do other motions interfere with this pull?

Hang a weight on a spring balance and move it in different directions. Does it still weigh the same? (Yes.)

John, how much do you weigh? Would you weigh more, or less, if riding along on a bicycle? On a fast train? Going up in an elevator? Coming down? (The same.)

Could you play ball on a swiftly moving steamer? (Yes, except for the wind.)

If a cannon were loaded, what would keep the ball from falling? (Bottom of the bore of the cannon.)

If the ball were loose and the cannon's mouth slightly tipped down? (Roll out.)

What would it begin to do the instant it was out of the cannon? (Fall.)

Suppose the ball back again, and, instead of tipping the cannon, let us *fire* the ball out. Will it again begin to fall the instant the cannon ceases to hold it up? (Yes.)

While it is falling what other motion will it have? (Straight forward.)

How long will it have to go ahead? (As long as it takes to fall to the ground.)

How many ways will the ball be moving at once? (Two.)

Do either of these interfere with the other? (No.)*

Resultant Motion.—All have been downstairs. What two ways did you go at once? (Forward and down.)

Yes, you *might* have walked straight along the upper floor till over the lowest step, and then taken all the *down* at once by—? (Jumping.)

Who has rowed across a river? Well, Samuel, tell us about it.

* I trust the class will be bright enough to raise some objections here at this difficult point. If so, a most helpful review can result.

"I had to row a little *upstream* all the time, as the current carried me down so fast."

How many ways did you then move at once? (Two.)

Who can draw a diagram on the board to illustrate these two things (stairs and boat)?

Now watch me while I carry this ball at the height of my head to the other end of the room and then drop it down into this basket. Who can suggest an easier way to get the ball from my desk to the basket? (Throw.)

Yes, but how? What motion shall I give the ball? (Straight ahead.)

What will make it go *down*? (Gravitation, or the attraction of the earth.)

Now watch while I try! (Throw *gently* at first.) Why did it fall short of the basket? (You did not throw *hard* enough.)

What difference did that make? (It did not have time to pass over the horizontal distance before it reached the floor.)

What must I do? (Make it go *swifter*.)

Now watch it! What was the path it followed? (A *curve*.) Who can draw a diagram of this?

Continued, what would a "curve" become? (Circle or ellipse or parabola, etc.) Explain the difference.

I want you to watch the flight of balls and such things and see if they always take this curved path. A boy puts a **stone in a sling** and whirls it rapidly around; while in the sling the stone travels in a——? (Circle.)

Does it *pull* on the string? (Yes.) Showing that it wants to go *straight forward*.

The moment the sling is loosed the stone——? (Flies off.)

A **carriage wheel** revolves rapidly. As it goes through the mud some sticks to the wheel, but the rapid motion makes it fly off and "spatter." Why? (The mud is more and more inclined to leave the wheel and go in a

straight course—inertia—till at last this tendency to keep *straight on* is stronger than the adhesive power of the mud, and off it goes.)

Huge grindstones, used to polish steel things, and driven at a high speed, are apt to *burst* and injure the men working about them. Why do they burst? (There is a force which holds the stone together, but the rapid whirling motion causes the outer portions to *pull* in their effort to move straight ahead, till at last pieces do fly off if the motion be swift enough.)

Put a **cupful of colored water** in a round fish globe; tie a cord about the neck and suspend by a long string from the ceiling; whirl the globe around in the direction of the hands of a watch till the string is *well* twisted, and then give it one whirl in the opposite direction. The twisted string will keep up the motion, and the water *rise into a ring* around the largest part of the globe.* Why does it rise into this ring? (Inertia.)

If elastic hoops, a ball of soft clay, or a drop of melted metal or rock could be rotated in the same way, what would happen? (*Bulge* at the *middle* and *flatten* above and below.)

Scientists have found that our **earth is twenty-six miles smaller** from pole to pole (show on a globe) than through the equator.

How do you suppose that happened? (Daily revolution.)

But if we are spinning around at such a rate why does the earth not fly to pieces? (Is not spinning fast enough to overcome gravitation.)

Why do *people* not fly off? (Gravitation holds them on.)

What else is held on by the attraction of the earth? (Name a number of things.)

* A rotator or whirling table will, of course, be better if one is to be had.

What causes the **barometer*** to rise and fall? (Weight of the air varies.) Then the air has *weight*; and weight is the measure of what force? (Gravitation.)

Does the attraction of the earth extend to the air? How high? (To the top.) That there really is an upper surface to this ocean of air that we live at the bottom of, is shown in various ways. One is, that "**falling stars**" (see Lockyer, chap. xi) only become visible at a certain distance above the earth. The space through which the earth is moving seems to have a great number of fragments of cold stone or metal, which are swiftly moving, like the earth and moon, about some center. As the earth travels on in her journey around the sun many of these come so near that they are attracted to the earth, and fall so swiftly through the air as to *take fire—burn up*. What makes them come to the earth? (Gravitation.)

Then the earth not only attracts rocks and people and air, but bodies *beyond* the air.

Who can now tell why the **moon goes in a circular orbit** about the earth? (*Earth's* attraction.)

Yes, we feel quite sure that is what keeps her from flying off. But the attraction alone would make her do what? (Fall to the earth.)

What made the ball, etc., move in a curved line? (A double motion—*onward* and *down* at once.)

So, what other motion must the moon have? (*Onward*.)

Illustrate on the board this continual *falling*, but, *while* falling, having an *onward* motion, by which it never gets out of its curved orbit. Always trying to fly off, like the stone in the sling, it is restrained by the attraction of the huge earth, and so travels about her—once in how often? (About a month.)

* See Step XV.

Can it be that this powerful force **reaches out to the sun?**

We might reply, Why not? We agreed that everything attracted everything else, and the great sun must not be left out.

Were, then, the ancients right in saying the sun revolved around the earth? (No, for we know the reverse is true.)

Why must this be? (The sun is so *very* much larger.)

Imagine for a moment that a boy had a stone weighing a *ton* in his sling: which would be forced to go around the other? (The boy.)

Yes, and so the sun holds the earth in her orbit, as the earth holds the moon.

How many motions must the earth have to do this? (Two: a falling and also an onward motion.)

Class now copy Fig. 41, p. 93, of Lockyer, and with these in hand further discuss this: how that, at every point in its orbit, the inertia of the earth impels in a *straight* line, which the continual pull of the sun changes into a curve.

Tides.—That the sun attracts the earth is plain. Does the moon also attract the earth? (Yes, for the earth is only another of the “everything’s.”) But we have very plain evidence of this pull in certain things which can be seen every day on the seashore. Twice a day the water about the wharves and along the shore *rises* for six hours and then falls for six. This rise and fall is called the tide, from a word which refers to its regular occurrences. What are two ways in which land can be flooded with water? (A *rise* of the water or *sinking* of the land.)

It was long ago noticed that as the moon rose in the sky the tide rose, and soon after she began to descend in the west the tide began to fall.

Why was this? (The moon raised the water.)

When I brought the magnet across the room toward the magnetized needle how did *distance* seem to affect the result? (The less the distance the stronger the attraction.)

Now the earth revolves on its axis once in — ? (Twenty-four hours.)

The moon goes around the earth once in — ? (About thirty days.)

(Illustrate this with the large and small globes.)

So the east coast of America (see map) is constantly coming *toward* and *passing by* the moon. The Atlantic Ocean lies directly under the moon some hours before this east coast does, and the moon, by its attraction on the near water, raises a wide ridge of water. As the *land* comes under the influence of the moon it is too stiff to rise, and so slides right into the ridge of water, which rushes up on to the land and makes the "rising tide" for six hours.

As the moon is left behind, her influence on the water becomes less and less, and the "tide *falls*" for six hours.

Class now copy on chart the illustration of the tides in Burritt, p. 284 (lower cut), or some other which shows the earth, sun, and moon at "spring" and "neap" tides.

With these in hand and a large copy on the board, an ordinary class will soon remark the high tides on *both* sides of the earth at the same time, and will learn that the swing of the earth about an axis a little nearer the moon than the true axis causes a tidal wave opposite the moon, just as the water on a grindstone that is hung on an axis a little to one side of its true center tends to fly off most at the point farthest from the axis.

They will also learn how to explain the cause of the varying height (spring and neap) of the tides, due to the combined or opposed attraction of both sun and moon.

This will end the work of this step, except the **Constellations**.—Choose those connected with the story of the Golden Fleece (Bulfinch, p. 158, etc., Greek Heroes, p. 107, or Tanglewood Tales, p. 180). The work as arranged will bring this step the last of October or first of November, when **Aries**—already found in the zodiac—can be seen. The myths connected with this ram were given in the previous step (XXIV).

Gemini were also found and spoken of at that time. Find again in January or February.

Lyra, the harp on which Orpheus played with such skill as to cause the ship to move off the beach with all her crew on board, can be found in the south and southwest during September and October, or again in April or May in the northeast (see Burritt, p. 112, and Bulfinch, p. 227). Its chief beauty is in the brilliant star Vega.

Cygnus—the Swan—lies in the Milky Way, just east of Lyra, and can be seen above the Harp in the fall or following it in the spring and summer. It is easily found by the two lines of bright stars (in the body and wings) forming a cross. One myth tells us that after his death Orpheus was placed as this constellation—next his harp. From these constellations pass to a review of Draco, Ursa Major, etc.

The age of pupils taking this step will be from eleven to thirteen, and it will not be impossible for the teacher to gather them at some elevated place, where trees or buildings do not interfere with the view of the sky, for an occasional **observation lesson**.

Choose, if possible, some platform or roof where the dew and dampness of the ground will not endanger health, and have several dark lanterns or other shaded lights at which they can consult maps of the stars and other aids. If cool, some place to warm at is a help.

Railway stations, where there is but little travel, often meet all these conditions well.

In any case continue the making of diagrams of the constellations, and add them to the portfolio before suggested (Step VII).

Clarke's astronomical lantern is a useful piece of apparatus, which I think the manufacturers (D. C. Heath & Co., Boston, Mass.) would not object to having bright pupils copy. It consists of a tin box with a ventilator on top, and places for two candles (or small lamp) inside. A groove above and below the open front holds a sheet of glass to protect the light when changing the cards. These cards are the same size as the glass, blue ground with white stars, and slide in the grooves outside the glass.

Bailey's star lantern is a very useful thing. The next step in this work is XXXV.

STEP XXXI.—THE STUDY OF MOLECULES.

An outline of experiments to show another way sharp stones might be made. See Step XX.

Object of these Lessons.—Primarily, to clear the way for future work along all lines, as experience has proved the *great* value of clear and correct ideas regarding the molecule and molecular structure. Whatever future science may disclose, the molecular theory has proved a powerful aid in all physical teaching; so efficient that I never should attempt to give ideas of heat, light, sound, etc., without *first* studying “the molecule.” To those who may urge its unfitness for eleven-year-old pupils, I can confidently point to more than one class of nine-to-ten-year-old children who have in after-work plainly shown the results in clear and accurate grasp of problems involving such explanations.

2. This work is a broadening of the child's horizon in physics, and an introduction to exact experiments and note keeping. While much has been brought to notice in minerals, pebbles, sharp stones, etc., it was *only* for notice, and now, with added experience and brain power, we invite the pupil to look *closer*.

3. To acquaint the child more fully with the admirable “metric” system of weights and measures, that the day may be hastened when it may replace our present antiquated and cumbersome system. For previous work on metric measure and volume, see Steps XXI and XXVI.

MATERIAL NEEDED.

The advanced nature of the work will require a corresponding outlay in time and money.

Tables should replace the school desk, as alcohol and acid would mar, and the slanting surface prevent many experiments; but be *very* economical in these, as a few pine boards twelve inches wide will answer well. Place these rough tables (breast high for the standing pupil) in some spare room, if possible, where things can be left without the breakage and loss of time due to daily getting out and storing away. Should no such room offer, two-foot (wide) tables might be stood on edge or hinged against the wall of the room when not in use, and could be quickly lifted on top of the desks. Each pupil should have three feet in *length* of space, or five feet for two pupils.

Some place to store the apparatus will be needed, especially where it has to be gathered up at the close of each lesson.

In this case have wooden trays or boxes for each thing (or for each pupil).

Water will be needed in plenty, and jars to hold the waste.

Quantity and Cost.—(For a class of thirty to work in pairs.)

15 50 c. c. graduated cylinders (glass).

15 droppers (rubber bulb). Make the opening *small* in a flame.

30 8-ounce wide-mouthed bottles of clear glass ("morphine" good).

30 3-ounce wide-mouthed bottles with good corks.

15 feet rubber tubing $\frac{5}{16}$ of an inch in diameter.

30 vials and corks, and 1 pound of No. 10 or "dust" shot to fill them.

Half a pound of hydrochloric acid.

1 quart alcohol.

15 4-ounce flat-bottomed, wide-mouthed, and strong glass flasks.

15 rubber corks (1 perforation) to fit flasks.

2 pounds thick glass tubing (small bore) to fit rubber corks.

1 triangular file to cut glass tubing.

2 pounds bullets or buckshot (largest to be had).

Quarter of an ounce iodine in bottle.

2 pounds eightpenny wire nails.

30 small bar magnets. (See Step III).

Expansion apparatus. (Rod and indexing needle.)

Expansion ball and ring.

15 3-ounce alcohol lamps (glass).

1 pulse-glass.

6 pudding dishes, flat-bottomed and 10 cm. deep.

15 "return balls" (ball on piece of rubber cord).

8 dozen glass marbles, uniform size.

30 slate pencils. 30 skewers from butcher. 30 pieces copper rod (or wire nails will do). All these nearly the same length and size.

30 5 × 8 inch notebooks, opening at the *end* and having wide ruling. Paper tough, and not too highly glazed (for pencils). It is better for the *teacher* to get these, as it saves one half to one third the expense, and secures a very helpful uniformity in size and quality.

The above is a good, serviceable outfit, and the most economical, as the *teacher's* time is too valuable to be spent in devising apparatus when it can be so cheaply bought.

The original outlay will be about one dollar per pupil, and will last for *years*.

The actual expense per lesson is about one cent for eight pupils, and after a trial no one will ever again hesitate on account of *cost*.

Breakage can hardly be avoided, but has been lessened by placing twenty-five cents to the credit of each pupil—to be his if he breaks nothing; otherwise applied on payment of damage. Post a *cost* list of all apparatus, both to aid pupils wishing to experiment at home and for settlement of damages.

Preparation of Teacher.—Tables having been prepared and apparatus got and put in order, go through the following lessons, step by step, till the subject is mastered and apparatus proved.

Should you be new at such work, find, if possible, some more experienced friend to advise and assist; but do the experimenting personally. Two or three bright, reliable pupils can assist—or, better, go through the experiments at the same time—and will afterward be able to render efficient aid in handling a large class.

Cards.—By the aid of hectograph or printer prepare fifteen cards of each experiment like those in the following “experiments.” Otherwise the experiments must be placed on the blackboard and copied.

Time.—About twenty-five or thirty lessons of thirty minutes each, at such time of the day as the schoolroom will permit. This, in places where there is no special room, had best be after school hours. Dismiss the rest of the school, and turn the room into a laboratory.

OUTLINE OF WORK.

1. What is a molecule ?
2. How *large* ? Ex. 1.
3. What is a possible *shape* ? Ex. 2.
4. Are there *spaces* between them ? Exs. 3 and 4.
5. Can molecules be *forced* nearer together ? Ex. 5.
6. What *holds* them together in solids, etc. ?

Cohesion, Ex. 6; adhesion, Ex. 7; gravitation,
Ex. 8.

7. Effects of *varying strength* of these forces.

Solids, Ex. 9 ; liquids, Ex. 10 ; gas, Ex. 11.

8. Are the molecules of these *still*, or in *motion* ?

Ways they may move. Ex. 12.

Work needed to change their state.

For work we can get :

1. Change of place. Ex. 13.

2. Change of shape. Ex. 14.

3. Sound. Ex. 15.

4. Light. Ex. 16.

5. Magnetism. Ex. 17.

6. Electricity. Ex. 18.

7. Heat. Ex. 19.

9. If work does *one* thing, it can not at the same time do as much of something else.

10. The *effects* of heat vibration.

Expands solids, Ex. 20 ; liquids, gas, and vapor.
Ex. 21.

Sets in motion (convection) liquids, gases, and vapors. Ex. 22.

Melts solids, vaporizes liquids, and decomposes gases. Ex. 23.

11. *How* are the heat vibrations *transmitted* ? (Conduction.) Ex. 24.

12. Do *all* substances transmit vibrations *equally well* ? Ex. 25.

13. Is much *force* exerted by expansion and contraction ?

14. What is the effect of *sudden* expansion or contraction ?

15. How might rocks have been cracked into sharp fragments ? (Continues Step XX.)

THE LESSONS.

I trust your pupils have been permitted to be your confidential assistants in all the preparation of orders for apparatus, unpacking, washing, and putting away. If this has been the case, they are now anxiously waiting, and no time should be lost.

Lesson 1.—What is a molecule?

In order to explain what we see about us, scientists have been obliged to suppose *all* things we see made up of tiny parts called molecules. Glass, iron, water, and air are, one and all, composed of the molecules about which we are now to study; and *a molecule is the smallest particle of anything which retains its identity* (is itself).

You may do what you please to salt—crush, pound, heat, cool, or dissolve it—but just as long as the tiniest particle of it remains *true to name* it is still *salt*; the smallest conceivable particle will be a molecule of salt. But if I in any way change it so that a quantity is no longer white, salt to the taste, nor will crystallize in cubes, I have destroyed the molecules of *salt*, and they become molecules of something else, or split into still smaller pieces called *atoms*.

Talk of sugar and other substances till this is clear. Have some of the chief points *briefly* but neatly recorded in the pupils' notebooks, reserving at least a *full page* for each experiment, so as not to crowd the notes.

Lesson 2.—Assign tables. Arrange class in *pairs*, with instructions that the pupils are to *take turns* in conducting the experiments. (If one is found doing *all* the work, the case calls for remedy.) Give each pair a card like the following, and the apparatus needed.

Experiment 1.—How large is a molecule?

Keep notes.

Measure 195 c. c. of water into one of two bottles, and fill the other with the same water. Do they look alike?

Into the water of one turn 5 c. c. of ammonia, add 1 drop of copper-sulphate solution, and shake or stir. By comparison with the other bottle of water (look through and also down *into* the water), can you see that the 200 c. c. are colored? Now count while you drop water with a dropper into the empty graduate till it stands at the 5 c. c. mark, and calculate into how many parts 1 *drop* of copper sulphate has been divided to color 200 c. c. of water.

After a reasonable time call the class to order and discuss results. These will vary somewhat, and the errors will introduce some needed instruction.

1. The graduates were *held* slanting, and some read the *top* and others the *bottom* of the curved upper surface of the water, etc.

Graduates in hand, show the class that accurate measure can only be had by placing the graduate on a *level* surface (mark the place with a pencil, and *always* stand it in its circle to read). Place the eye on the level of the surface and read the *middle* of the curve.

2. Errors in counting occurred. Show how unreliable *one* trial is, and get them to suggest ways of preventing error. (Recount and average results, if nearly alike, or make a third count and reject the one most out of the way. Let another boy try it with the same dropper; drop 10 c. c. and divide by 2, etc.)

3. The 200 c. c. of water was not seen to be colored by some. Question as to what they did, and bring out the need of *exactly* following instructions and the use of a

standard for comparison (bottle of water like the 195 c. c., into which *nothing* was put).

4. Some did not know how to calculate the result. Let the teacher here write a model set of notes on the board and work it out with the class as follows:

Experiment 1. Question.—How *large* is a molecule?

Apparatus, 50 c. c. graduate, two clean bottles, clear water, and dropper.

1. Put 50 + 50 + 50 + 45 c. c. water in bottle = 195 c. c.

2. Filled the second bottle with same water.

3. They looked alike.

4. 195 c. c. water + 5 c. c. ammonia = odor and 200 c. c.

5. (4) + 1 drop copper-sulphate solution = bluish-white flakes.

6. Shook (5) and flakes disappeared.

7. Compared (6) with (2) and noticed a *bluish tinge*.

8. Emptied graduate and counted drops in 5 c. c. water = 96 drops.

9. Tried (8) again = 105 drops.

10. Tried (8) again = 97 drops (reject (9)).

11. Thomas tried (8) = 95 drops.

12. Average drops in 5 c. c. from (8), (10), and (11) $\left. \begin{array}{l} 96 \\ 97 \\ 95 \end{array} \right\}$
 $= \frac{288}{3} = 96$ drops.

13. $200 \text{ c. c.} \div 5 = 40$. $40 \times 96 = 3,840$ drops in 200 c. c.

14. Conclusion: 1 drop copper-sulphate solution was divided into 3,840 parts. Rather small!

This may seem tedious work, but the class has been well occupied and no time really lost.

Endeavor to complete this in one lesson (while fresh in mind), for the inspiration which comes from "something attempted, something *done*" each day.

Lesson 3.—Spend **two minutes** in a brisk **review** on yesterday's work. Then on the board average the results

of the whole class as to drops in 200 c. c. water. (My result has been about 4,600.)

Tell the class that the drop of copper sulphate solution was only about $\frac{1}{8}$ copper-sulphate, and the rest was — ? (Water.)

Write the chemical symbol (CuSO_4) on the board. This stands for the least possible bit of copper sulphate. What do we call it ? “A *molecule*.” But in chemistry “Cu” stands for an atom of copper, “S” for an atom of sulphur, and “O₄” for 4 atoms of oxygen.

How many atoms in a molecule of CuSO_4 ? (Six.)

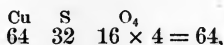
Here show pieces of copper and sulphur about the same in size.

Pass them about, and tell me which is *heaviest* ? (Copper.)

Air is about like oxygen. How does that compare with the others ? (Lighter.)

Scientists have weighed these carefully, and find an atom of O to weigh 16, S to weigh 32, and Cu to weigh 63.4 times as much as an atom of the gas (hydrogen) they have selected as the standard of weight for atoms.

Calling 63.4 an even 64, and writing the symbol thus,



we see that the $\frac{1}{8}$ copper sulphate in our drop of solution was only $\frac{4}{16}$ copper by weight, and so our division of real copper becomes 200 c. c. \times 23 (drops in one c. c.) \times 8 \times 2 $\frac{1}{2}$ = 4,600 \times 20 = 92,000 parts, the copper in each drop of solution was divided into more than the seconds in a whole day ! And each of these 92,000 parts was doubtless made of *many* atoms of copper !

A wise Englishman (Sir William Thompson) has studied this matter, and gives this illustration :

“If a drop of water were magnified till as large as the

earth, the molecule would then probably be larger than shot, but not as large as cricket balls" (or apples).

Try and conceive the number of balls or apples needed to fill this great earth if it were a hollow sphere.

So much for *size*.

Experiment 2.—What is a possible **shape** of a molecule?

Examine a vial of fine shot and write your conclusions.

State clearly to the class that we *know* nothing of the shape; but have the pupils name other shapes, and see the difficulties in supposing them to be other than *spherical*.

Lesson 4.—Are there spaces between the molecules of water?

Experiment 3.—To 75 c. c. of water add 25 c. c. of water (measured separately), and record its volume thus: $75 + 25 = (\quad)$. Now, to 75 c. c. water add 25 c. c. of alcohol; shake, and record as above. To 75 c. c. of water add 10 c. c. of salt, and, when dissolved, record volume.

NOTE.—The weak alcohol made is worth saving, but throw the salt solution away. For measuring the salt select a small tin box that will hold about 10 c. c.; measure it carefully, and write the volume on it to substitute for "10 c. c." if it differs. The graduate is *wet*, and the salt will stick in it. Results of careful measuring will be about 100 c. c., 96 c. c., and 76 c. c. for these three trials.

Experiment 4.—Are there spaces between them for gas?

Apparatus: Flask and rubber cork, small bottle and good cork, cork borer, a 30 cm. and an 8 cm. bit of glass tube, 30 cm. rubber tubing, piece of marble or limestone size of hickory nut, 5 cm. squares of window glass, and some dilute hydrochloric acid.

A wide dish, flat bottomed and 10 cm. deep, will

be needed for each six pupils (pudding dish or milk pan), and an alcohol lamp.

There is so much new to the pupil in this experiment that the teacher had better go through it before the class first. Proceed as follows :

All take your notebooks and write what I tell you to write while showing how to answer this question.

1. I take this piece of marble, wrap it in a number of thicknesses of paper, and crush with this hammer. I now open the torn paper over a whole sheet, and pour the marble into this small bottle. Write: "1. Break marble and put it in small bottle."

2. I light the alcohol lamp, and, holding the middle of this 8 cm. piece of glass tube in the upper part of the flame, slowly roll it around so as to heat all sides equally. Now it begins to feel flexible in the middle, and I slowly bend it to a right angle and lay it on this board to cool. Why not lay it on iron or cool in water? (Break.)

I was careful not to twist or push on the tube while soft, and by slowly bending before it got red-hot the hole through it is still round and open. Write: "2. Bend 8 cm. tube."

3. I take this sound (solid and free from holes) cork and try it in the bottle holding the marble. It fits. I now choose this cork borer, a little *smaller* than the bent tube, and with a twisting motion push it slowly through the cork, which I place against another cork. "Why?" Watch while I make this second hole half an inch to one side of the first. (Breaks a piece out as it comes through.) Why not bore against this hard wood or a piece of iron? (Dull the cork borer.)

In one of these holes I push one arm of my bent tube, which I first soap and then twist in, as I did the borer.

Now watch while I cut 30 cm. off this long glass tube for a "safety tube." Having measured, I take this three-cornered file and draw it three or four times across

the place, making a nick. Placing my thumbs firmly on either side of the mark, I give a quick bend to the tube and it snaps squarely off at the mark. Soaping my safety tube, I twist it into the second hole far enough to just clear the marble in the bottle when the cork is tightly in.

Now I stick my two forefingers into the end of this piece of rubber tube and pull, so as to turn a little of the end inside out, and, pushing this inverted end against the upper end of my glass "elbow," slip it on a little way. Write: "3. Bore two holes in cork, insert elbow, cut 30 cm. safety tube and insert, and slip rubber tube on 'elbow.'"

4. These rubber corks have a hole which we do not need for use now. To close tightly, I slip in any *solid* round thing which fills the hole tightly (bit of pencil, wood, or glass rod). Now I see that the cork fits the mouth of this flask. It does. Write: "4. Plug hole in rubber cork and fit to flask."

5. I *half* fill this large dish with water; fill *brimful* the flask and set it in the water, while I pour half an inch of water into the small bottle, covering the marble. Write: "5. Fill flask, half fill dish, and put half an inch of water on the marble."

6. I take this square of clean glass and lay it on the top of the brimming flask. A little air bubble shows under it, so I remove and pour a little water into the flask, and again place on the glass. No air shows; so, holding the glass in place with my right hand, I raise the flask with my left and turn it upside down. No water can run out. Still holding the glass in place, I lower flask and all till the mouth is entirely below the water in the large dish, and, slipping off the glass, stand the flask bottom up. Why does not the water run out? (See Barometer in 16, Step XV.) Write: "6. Invert flask in large dish of water and hold from tipping."

7. John may hold my flask while I pour about half a

teaspoonful of this acid on the marble and quickly push the cork tightly in place. See the bubbles of gas come off. Do not pinch or kink the rubber delivery tube in any way while you dip the end below the water in the dish.

The bubbles coming freely from its mouth tell me all is working right, and the safety tube prevents danger of an explosion. Now I slip the end of the rubber delivery tube (as it is called) below the mouth of the slightly tipped flask, and the bubbles of gas rapidly rise to the top and push out the water. The flask is now half full of gas, and removing the rubber tube, I place my hand *under* the water and slip in the rubber cork as tightly as I can and not break the flask. Write: "7. Put half a spoonful of acid on marble, cork tightly, and when gas is coming off freely run it into the flask till half the water is pushed out. Cork *under* water."

8. Keeping the corked mouth of the flask down, I raise it out of the water and look at the neck. See the little bubbles of *air* rising through the water. The cork is loose. I quickly put the mouth under water again to stop the air getting in, and give the cork a twisting push to make it tight, for no air must enter. Trying again, no bubbles show, and I now shake the flask in this way (violently) for a whole minute, and replace the mouth at once below the water in the dish. Keeping the mouth carefully covered, I grasp the cork. Now, the question is—what? ("Are there cracks in water into which molecules of gas can get?") Watch the surface of the water in the flask while I twist out the cork. (*Water rises!*) We will not discuss this now, but recork the flask and shake again. (*Rises more.*) Try still a third time. (*Rose again.*) Write: "8. See that no air enters when flask is removed from the water, and shake one minute. With the mouth *wholly* under water, watch the surface in the flask carefully while the cork is slowly twisted out. Recork, and shake again twice."

This is all to-day. To-morrow all try this and write your notes.

Lesson 5.—Spend not over five minutes in a brisk review of the instructions given yesterday, and then let the class go to work.

Experiment 5.—**Can the molecules of a solid be forced nearer together?**

Have sixty big bullets ready, and as soon as some of the class are through and have notes written let them find the volume of the bullets as follows:

1. Roll or drop the bullets gently into an inclined and dry graduate (so as not to break the glass). If the sixty pieces rise above the 50 c. c. mark in one, divide them between two graduates.

2. Measure *exactly* 50 c. c. of water, if bullets are in *one*, or 100 c. c. if in *two* graduates.

3. Pour this measured water on the bullets till covered, and the water stands exactly at the 50 c. c. mark. How much water is left? (The volume of the lead.) Record all the above.

A second pair of pupils (who know nothing of the results found) may now roll the lead in a towel till dry and try again. Call the class to order a few moments before the close of the lesson. Let them place the figures found regarding the lead under the head of Experiment 5, and give each two bullets to find if the molecules of a solid can be *forced* nearer together. Caution them to pound into some regular shape (cube or prism) on a clean iron surface, and to pound *hard*, and return them to-morrow to see if they measure less.

Lesson 6.—Experiments 3 and 4 have now been tried. Gather the pounded bullets and measure again for the class to complete the notes regarding (5), which should be as follows:

1. Sixty bullets measured, say, 39 c. c. = .65 c. c. in each.
2. Pounded each one hard on clean surface.

3. Sixty pounded bullets measured $37\frac{1}{2}$ c. c. = .625 c. c. in each ; $.65 - .625 = .025$ c. c. loss in bulk.

Yes, the molecules of lead can be forced closer.

Experiment has now proved that liquids (alcohol), and gas (CO_2) can find their way among the molecules of water, and that solids can be compressed (lead).

Does this answer the question of Lesson 4 ?

(Molecules *do* have spaces between them.)

Do all molecules seem to be of the same size ? (No, for alcohol, gas, and salt could get between those of water.)

Illustrate this by the following story of

THE REMARKABLE BARREL OF APPLES.

A grocer bought a barrel of very large and sound apples, and, removing the top cover, placed it in front of his store to attract buyers. Who can tell me just how it looked ?

Yes, they *were* rosy and smooth, a few top ones were slightly flattened, and between them were crevices, although all touched and were still.

As the barrel stood there a man came out with a paper bag of beans and laid it on the apples. On picking it up the bottom gave way, and out spilled the beans on the apples.

As he went back into the store for another bag, some men who stood by decided to play a joke, and shook the apple barrel till the beans had almost disappeared. The man complained to the storekeeper that he had lost his beans, and wanted to empty out the apples and get them ; but he refused, as he said handling injured the apples, and, gathering up what lay on top, gave the man some more. Soon after a child came out with arms full of bundles, and finding they were in danger of falling, tried to drop them on the apples. One package fell heavily, and out burst a lot of granulated sugar.

The mischief-making men were standing by, and, as

the child went in to tell the storekeeper, slyly shook the barrel till the sugar had almost disappeared. Where? The grocer was much displeased, and scolded the child for making "a sweet mess of his apples," and wanted her to go home without her sugar; but the jokers were brave enough to tell of their part in the matter, and offered to pay for the sugar if they might see if anything else could be got into that barrel. What else would go in do *you* think? Yes, they tried *water*, and poured in quite a quantity before the barrel was really full. Even then one of them said, "That barrel is not full yet!" Most of the crowd laughed at the idea of getting anything more in. Would you have done so?

At last one man said he would pay the cost if anything bigger than a *pin* could be got in. So the man who said the barrel was not full tried—what?

Yes, he brought a jug of alcohol, and, by adding a little at a time, really put in quite a quantity.

At last it would hold no more, and most supposed *that* barrel was full. But a chemist who stood by said, "Not yet. I can't show you with that open barrel, but will show how it could be done with this bottle of water;" and really did so. What did he do? ("Dissolved gas.") Just as we did! True enough. This barrel of apples helps us to understand how a thing can be full of *one* thing and still have room for more of something else. But there are two things about the apples *very* unlike the molecules of this water or lead; for we have good reason to think the **molecules neither touch nor are still.**

A book I am much indebted to, by Mr. Stewart, of England,* illustrates this by the stars, sun, and planets.

After speaking of the Milky Way and its myriad stars, of our sun, the nearest star, and its planets and their moons, he uses these words: "Now, just as in the

* Elementary Physics, p. 2.

starry firmament there are vacant spaces between the various individual stars, so in the small scale there are probably vacant spaces between the various molecules of a body."

So I want you all to think of the molecules of glass in this tumbler, or of steel in this knife, as *separated* on *all sides* from each other, just as the earth, moon, and sun are, and hence with plenty of room to move in.

To further illustrate, let me draw these dots on the board; the spaces between them are *much* larger than the dots themselves. I know what you want to ask, and to-morrow we will try and find how it happens that the glass and lead are not shapeless heaps of molecules.

Lesson 7.—A brisk review of the lessons so far; then proceed.

We find molecules *very* small, probably *round*, of different sizes in different things (the same size in each), and that they do not touch each other.

The next question is, **What holds them together?** We have many sets of words which express different states or degrees of the same thing. We say "a breath," "a breeze," "a gale," "a tempest," of *wind*. So we use the words "touch," "tap," "slap," "blow," to tell how a thing came against us. Again we say, "The flowers *attract* bees," "The child *draws* his wagon," "The lion *tugs* at his chain." So we have various words for the force or forces (for we are not *sure* they are the same thing) which try to hold molecules together, and we will experiment about two to-day. Push your experimenting *vigorously* and we can finish both. (Give cards and material.)

Experiment 6.—**Cohesion** binds molecules of the **same kind**.

Try to stick two pieces of chalk together.

Two pieces of dry glass.

Two pieces of bright lead.

Two pieces of clay (moist).

Two pieces of cold wax.

Warm the wax and try.

The force which holds molecules of the same kind together is called cohesion.

Does it act at long distances, or short ?

Record other examples.

When Experiment 6 is complete, give

Experiment 7.—Adhesion binds molecules of **different kinds**.

Try to shake a lead pencil mark off a piece of paper.

Wet two pieces of glass and see if they stick together.

Dip a glass tube in water, and, holding it up, write what you see.

The force which holds different molecules together is called adhesion.

Does it act at long distances ?

Give other examples of adhesion, and record.

Lesson 8.—A two-minutes review of yesterday. There is a third force tending to draw things together, which we will learn more about to-day.

Experiment 8.—Gravitation draws all things together.

Lift some lead 1 cm. and let go.

1 M. and let go.

As high as you can and let go.

Repeat with two other substances.

What did they do at all distances ?

The force which causes this is called gravitation.

Record other examples. (See Step XXX.)

To test this still further, and see whether it acts on air and water as well as the things you have tried, suspend your 30 c. c. bottle by a fine wire 1 m. long (measure from the center—inside—of the bottle to the screw the wire is fastened to). Set it swinging from side to side, and count the number of times it passes the center

in one minute. Prove by counting again. We call such a thing a *pendulum*.

What makes it swing? What is the bottle filled with?

Now fill (without untying from the screw, lest you change the length) with lead and count twice.

Fill with sand and count twice.

Fill with water and count twice.

Lesson 9.—What are the three forces (as we call them) found trying to keep molecules together? (Cohesion, adhesion, gravitation.)

Which act at *short* distances only?

Which at all distances?

Which between like molecules? Unlike molecules? All molecules?

What is a pendulum? What makes it swing? (Gravitation.)

How do you find the length (*center* of weight to attachment)?

Kate and Mary may give me their counts to place on the board.

1. Full of — ? (air) = $\left\{ \begin{array}{l} 58 \text{ swings} \\ 62 \text{ swings} \end{array} \right\}$ average = 60 swings, or — ? (Vibrations.)

2. Full of — ? (lead) = $\left\{ \begin{array}{l} 59 \text{ swings} \\ 59 \text{ swings} \end{array} \right\}$ average = 59 swings.

3. Full of — ? (sand) = $\left\{ \begin{array}{l} 60 \text{ swings} \\ 60 \text{ swings} \end{array} \right\}$ average = 60 swings.

4. Full of — ? (water) = $\left\{ \begin{array}{l} 60 \text{ swings} \\ 59 \text{ swings} \end{array} \right\}$ average = $59\frac{1}{2}$ swings.

What do you notice about these averages? (Nearly alike.)

Yes, as nearly as can be expected, with our apparatus.

What do you infer from this? (*All things fall equally fast.*)

Which *way* do they fall? (Straight toward the center of the earth.)

What forces are acting on my ink bottle? (Cohesion holds glass molecules in shape, adhesion holds label and ink stains, and gravitation makes it press on the hand that holds it.)

(Multiply such questions, for the subject is far-reaching.)

To-morrow we will see the results of weak or strong cohesion and adhesion.

Lesson 10.—Omit review. Give Experiments 9, 10, and 11.

Experiment 9.—Try to twist, stretch, and squeeze together a piece of wood or iron.

Does it keep its shape?

Has it any hardness?

Such a thing is called a *solid*.

Write about this, and name five other solids.

Experiment 10.—Take 100 c. c. of water and pour it into four different shaped dishes.

Does it fit each one equally well?

What kind of a surface has it in each?

Has it any hardness?

Such substances are called *liquids*.

Name five others in your notes.

Experiment 11.—Push an “empty” bottle, mouth down, into some water.

Why does not the water enter?

Has air any shape?

Any level surface?

Any hardness?

Does it stick to things?

Does it seem to have any cohesion?

Such things we call *gases*.

Heat your flask hot, drop in a crystal of iodine, and see how the violet vapor fills the flask.

Lesson 11.—How would you know a *solid*? (Hardness and shape.)

How know a liquid? (Level surface, and always fits containing vessel.)

How know a gas? (Molecules fly apart, and fill any containing vessel, no matter how large. Has no level surface.)

Which of these has the strongest cohesion? (Solid.)

Do liquids have cohesion? (A little, as shown by drop of water.)

What held the drop to the glass tube? (Adhesion.)

Why did the water rise higher *inside* the tube? (Adhesion acting on all sides of a small surface raised it.)

What forces pulled the water down in the center? (Cohesion and gravitation.)

In which of the three classes did the molecules seem freest to move? (Gas.)

In which were they most fixed? (Solid.)

What was the intermediate stage called? (Liquid.)

By these experiments I have tried to give you the idea of the tiny molecules separated from each other by spaces and still held from getting clear away by these forces. What the forces *are* (or *is*, for there are many reasons for thinking the three really only *one*) which reach across all spaces from the tiny ones between the molecules which cohesion can span to the enormous distance between the sun and his planets, I have nothing to tell you, for no one knows. Perhaps some of *you* may be wise enough to find out in the future. Meanwhile, let us ask Nature another question about these wonderful molecules: **Are they still, or in motion?**

Experiment 12.—Make a pendulum of a bullet and thread.

See it swing back and forth.

Each swing is called a vibration.

Make it vibrate in a circle.

Take a "return ball" and see how it vibrates up and down.

What are three ways a thing can vibrate ?

Lesson 12.—Here is a ball on my desk. Unless something moves it, how long will it stay there ? (Forever.)

Suppose I threw it hard into some mud ? (Stopped by mud.)

If I threw it to another boy and he failed to catch it ? (Strike the ground.)

If thrown up, what force (that we have talked of) would stop it ? (Gravitation.)

Do you know of any case where it would not stop ? (No.)

If the ball got started and there *was nothing* to stop it, how long would it keep going ? (Forever.)

Hence we must conclude that nothing starts or stops unless made to do so. Now, molecules are "things" just as much as this ball, and if "still" it must be because they have never started, or have been stopped. If in motion, it is because something has set them going.

What do you call the act of a man who keeps a spade from "stopping" all day ? (Work.) Another man starts a pen and keeps that going, he — ? (Works.) A woman keeps the dust flying with her broom ? (Works.) A man pitches bricks to another ? (He works to keep up motion.) How about the man that catches the bricks ? (Works to *stop* motion.) So we might add many illustrations to show that all work causes a *change* from rest to motion or motion to rest.

Let us try some experiments, and see what work can do.

Experiment 13.—Toss something up and catch it again.

Repeat three times, and then write what work you did and what came from it.

Experiment 14.—Pound a piece of lead hard, and, touching it to your lips, write the result of your work.

Do the same with a nail.

Experiment 15.—Hold a shoe button on a thread near a bell and gently tap the other side.

What happens ?

Tap a tuning fork on the table and touch the prongs to the button.

Stretch a piece of India-rubber string and make it sound by pulling the middle to one side and then letting it go.

Watch it.

Write what you saw in each case.

Did you do work ?

What was the effect ?

Experiment 16.—Rub a match head quickly across a rough surface. What did you get for your work ?

Lesson 13.—Alice may read her notes on Experiment 13. "I set the ball in motion and stopped it again. For my work I got motion and rest."

What stopped it when going up ? (Gravitation.)

Did any one get something else from his experiment ?

James : "I think I moved the air." Yes!

Thomas : "I got *sound* when it hit my hands."

Charles may read about 14. "I did work in hammering, and got heat and change of shape."

Mary : "I also got *noise*."

Ralph : "The lead changed shape the most, and the iron got the hottest."

Samuel may read his notes on 15. "I held the button near the bell and struck the other side. The button danced out and back as the bell sounded. The tuning fork sounded and made the button fly off. The rubber sounded and seemed to fly from side to side. I did work in each case, and got *sound*."

Very good. Now Henry may read his notes on the match.

“Rubbed a match, and got sound, light, and heat.”
Yes.

They say that when the Government is testing its cannon the huge steel shot are fired against a strong target covered with iron plates. When the swiftly moving shot crashes against the target and is stopped and battered a flash of *flame* is seen.

What made the shot go? (Powder.)

What work did it do? (Changed shape of itself and target, made heat, flame, and sound.)

To-day we will try another way of changing the condition of molecules.

Experiment 17.—1. Dip a **magnet** into a box of iron filings, and, lifting it out, write what you see.

2. Replace all the filings. Place the head of a large tack against the magnet, and then let the end of it touch the filings. Raise and observe; then carefully take hold of the large tack and slide its head off the magnet. What happens?*

3. Take a large steel needle that has never touched a magnet and dip it among some iron filings. Do any adhere? Then stroke the unmarked end of the magnet with the pointed end of the needle (as in 5, Step XXV) ten to twenty times, and try again.

4. Suspend your needle by a long thread tied about the middle, and let it come to rest. Which way does the eye end point?

5. While waiting for the big magnet to get still, choose a cork which will float upright in the water, lay the needle on its top or run it through the cork so as to be parallel to the surface of the water.

* Teacher must be sure the tacks and filings are not *steel*, which is frequently used nowadays.

Set this afloat, and see which end points the same way as the marked end of the large magnet, and mark it by slipping on a bit of red paper. We now know which ends of our two magnets are alike and which are opposite.

6. Bring the *like* ends of the large and floating magnets near (must not *touch*) each other, and, after repeated trials with both marked and unmarked ends, write your observations.

7. Now reverse the 6th, and bring *unlike* ends near in the same way.

8. Break the needle in the middle, and, mounting one piece in the cork, use the other as the larger magnet in 6 and 7. Have you two half magnets, or two smaller *whole* ones ?

Lesson 14.—Review yesterday's work with magnets.

What does a magnet do to iron filings ? (Picks up.)

Do the iron filings seem to be magnetized when on the magnet ? (Yes, for others hang to them.)

Do they keep this magnetism after being removed from the magnet ? (No. A big tack held filings till it slipped off of the magnet, and then they soon fell.)

What are needles made of ? (Steel.)

Did the needle pick up iron filings before it touched the magnet ? (No.)

Tell me exactly how you magnetized it. (Stroked the unmarked end of the magnet with the pointed end of the needle.)

How do you know that made a magnet of the needle ? (Picked up filings, always pointed north and south, and acted like the large magnet when brought near it.)

You made the marked end of the needle by stroking which end of the magnet ? (Unmarked.)

Suppose you had wanted the eye of the needle to point *north* ? (Would have rubbed that on the unmarked end.)

Then the new magnet is just the opposite of the end stroked.

How do these unlike ends behave toward each other ?
(Attract.)

How did you prove it ? (By drawing the cork and its needle about in the water.)

How do *like* ends behave ? (Repel.)

How wonderful that, without *touching*, a thing can be pulled and pushed !

On breaking the needle did you get two halves, or two small magnets ? (Two small magnets.)

How did you prove it ? (One half pointed north and south, and the other drew and repelled it, just as the large magnet did.)

All these wonderful things we believe are due to an **arrangement of the molecules** in the iron or steel.

In which does this arranging only last while the magnet is near or touches ? (Iron.)

And steel ? (The molecules stay as the magnet fixed them.)

There is another way the molecules can be changed, which we will show by experiment to-day.

Experiment 18.—Electricity.

1. Hang a ball of pith by a silk thread from the end of your longest glass rod.

2. Rub a hard-rubber comb or ruler briskly on some fur or woolen ; bring it to the ball, and after three trials record what you saw.

3. Rub a large glass rod or tube (Argand chimney) briskly with old silk, and bring it to the ball. Repeat twice and record.

4. One rub the glass, while the other rubs the rubber comb, and present both to opposite sides of the ball for a minute. Record.

5. Place a pinch of light chaff or bran in a box cover about 15 mm. deep. Set this on a bare table, cover with a piece of clean and dry window glass, and rub briskly with the silk over the chaff. Record.

6. Rub the comb and hold it near the chaff.

Lesson 15.—When hard rubber is rubbed on fur or woolen, what can it do? (Pick up light things and attract and repel pith ball.)

When glass is rubbed with silk? (Chaff keeps flying up to the glass and back to the box, and it attracts and repels pith ball.)

We call the glass and rubber “electrified” when they do this.

Did the pith ball stick quietly to the rubber or glass? (No; after first touching, it was *repelled*.)

What happened when both were presented to the pith ball? (It vibrated from one to the other.)

Jane may read her notes on the 5th. “The chaff danced up and down, from the box to the glass and back. Some stuck to the glass a moment.”

Mary may read about 6. “The rubbed comb picked up the chaff and held it quite a while.”

Did any one *see* what it was that pulled and pushed the ball and chaff? (No.)

When the magnet touched a tack what did it do to it? (Magnetized it.)

When the electrified comb touched the ball, what happened to it? (Was electrified.)

We had two kinds of magnetism (at the two poles). Have the experiments taught you whether there are two kinds of electricity? (Yes; that in glass *drew* the ball, that in rubber *repelled*.) Correct.

We call that in glass “+,” and that in rubber (or sealing wax) “-.”

Who can tell me ways in which magnetism and electricity resemble each other?

“Two kinds: + from glass and - from rubber.”

Like kinds repel each other (ball thrown off and chaff).

Unlike kinds attract (pith ball between two kinds).

Both act in an unseen way across quite a space.

One more thing I want you to get for work.

Experiment 19.—Rub your hands together *hard*.
What did you get ?

Rub a metal button or coin on a woolen cloth. What ?

Find and record answers to at least two of the following questions :

1. Why are your hands blistered by sliding down a rope ?
2. How did the natives of north Asia get fire before having matches or steel ?
3. How did Gitche Manito light the "peace pipe" in Hiawatha ?
4. Why does a man throw water on the wheel over which the rope attached to the harpoon in a whale rapidly runs out ?
5. How does a saw or an auger bit feel after going through a hard board ?
6. Why do we oil the axles of cars, wagons, and machines ?

Was some kind of *work* done in each of these cases ?

Lesson 16.—Kate, what did you get by rubbing your hands ? (Noise, worn skin, and heat.)

Robert, you rubbed the button ? (Wore metal and cloth ; heat.)

Who has an answer to the first question ? (Samuel : "The rope heated the hands.")

The second ? (Jane : "The Chukches had a fire drill" ; others rubbed dry wood together.) (See Voyage of the Vega, pp. 311 and 312.)

How was the "peace pipe" lit ? (Susan reads selection from Hiawatha.)

The whale-boat line ? (Edward : "The whale sounds so rapidly when struck that the rope might set the boat on fire.")

Who has tried the saw ? (Paul : "It was hot.")

And the bit, or auger ? (Peter : "Almost burned my fingers.")

Why do we oil bearings? (Mary: "Would grow hot from friction.")

Was *work* done in each case? (Yes.)

What was obtained in every case? (Heat.)

We must not linger longer over this; so now tell me what things we have had in exchange for *work*?

1. Change of place.
2. Change of shape.
3. Sound.
4. Light.
5. Magnetism.
6. Electricity.
7. Heat.

In which can the eye see the change? (1, 2, and partly in 3.)

What did sound seem to be caused by? (A quivering motion.)

Let me give you **an illustration** of what happens when this quivering or vibrating becomes more rapid. Let us imagine a powerful engine in the basement of a tall building. Connected with it is an iron shaft running up to the middle of the top floor (beyond all sound from the engine), and in the end is fixed a horizontal rod half a metre long. A strong railing prevents any one getting in the way of this rod, as it swings round and round. Holding a light switch in our hands to feel the rod as it swings past us, we stop the machinery, and when all is still make the room perfectly dark and quiet. A secret signal is given to start the rod in revolution; once the first second, two times the second, three times the third, and so on up to any required speed.

How could we know the rod had started? (Feel a blow to switch.)

These blows would grow more and more rapid, and, laying aside our switches, we wait in silence. Every

time the rod went round it would push the air away, and we might possibly feel the puffs of wind, and could count them, "1, 2, 3, 4," etc. ; but when they reached *16 per second* we should know of the rod's motion in another way. You have heard a thrashing machine or planing mill. As the cylinder or saw began to move, we first heard a low grumble, rising higher and higher as the speed increased to a shrill pitch, falling when a bundle of grain or a board was put in, to quickly rise again as that piece of work was done, and another bundle or board prepared. So with our rod. We should at 16 vibrations (or revolutions) per second begin to *hear* a low note, which would rise higher and higher till the shrill sound was almost unbearable, and then ? (Silence.)

Yes ; our ears can not hear above a certain number of vibrations per second ; but already *another* sense is beginning to be touched, and while the increasingly rapid blows can not be heard, we can *feel*—what do you suppose ?

Yes, *heat*. As the rod's speed increases the heat becomes greater and greater till another sense is acted upon, and we—— ? (See.)

Have you ever observed a piece of iron get hot ? It is "black hot" at first, then comes a faint red, growing into yellow, and at last "white hot." Our rod would pass with the increasing vibrations from heat to a red ; then passing into orange, yellow, and white. The speed now would be *terrific* ; seven hundred trillions or more per second representing numbers totally beyond our imagination, and no *real* machine or rod could ever reach it. But our imaginary one can.

No sound, no heat, no light that we can know anything of. But had we a camera in the room, the rapid vibrations *could* still take a photograph of our astonished faces.

I have told you this to help you to understand what

heat and light are supposed to be—simply a kind of motion of the molecules.

Lesson 17.—When you did work, did you always get something for it? (Yes.)

Now a *very* important question. If work does one thing, can it at the *same time* do as much of something else? Think of this *carefully* before you answer.

Let us place our experiments in a table on the board and see. Each tell me of one thing in a scale of ten.

EXPERIMENT.	Motion.	Rest.	Sound.	Change of shape.	Heat	Light.	Magnetism.	Electricity.
Ball tossed	10							
Ball caught . . . .	.....	9	1					
Lead pounded	1	.....	1	7	1			
Iron pounded .	1	...	2	5	2			
Bell and fork struck	1	.....	9					
Rubber cord pulled	2	.....	8					
Match rubbed .	1	.....	1	1	4	3		
Cannon fired ..	7	.....	1	.....	1	1		
Target struck .	.....	6	1	1	1	1		
Magnet - raised nails	5	.....	.....	.....	.....	.....	5	
Magnet stroked by needle	1	.....	.....	.....	1	.....	8	
Unlike poles attract	8	.....	.....	.....	.....	.....	2	
Like poles repel	8	.....	.....	.....	.....	.....	2	
Rubbed comb ..	2	.....	1	.....	2	.....	.....	5
Rubbed glass rod	2	.....	1	.....	3	.....	.....	4
Rubbed hands .	1	.....	1	1	7			
Rubbed button	1	.....	1	1	7			
Climbed rope ..	3	.....	1	1	5			
Fire drill	3	.....	1	1	4	1		
Whale in diving	6	.....	1	.....	3			
Sawed board ..	2	.....	1	5	2			
Bored hole	2	.....	1	5	2			
Steam - moved cars	6	.....	1	1	2			

Do not compare one experiment with another, for the same amount of *work* was not done in each case. What shall we conclude? (No; **when work does one thing it can not be doing something else.**)

Let the teacher fully illustrate this far-reaching and important principle of the conservation of energy by talking of purchases with money (if we buy one thing, we must give up the chance to buy another, etc.); study (can not *play* at the same time); character, etc.

Another important question: Have we obtained any of these results *without* work? (Not a single one.)

If the amount of work is small, the results will be——? (*Small.*)

If much work is done——? (The results will be correspondingly *great.*)

There are few more important lessons I can teach you than this: That **nothing** in this world **is obtained without giving its equivalent**; and if we choose one thing, we must give up something else. Now, let us see some things we have learned of molecules:

They are *very* small.

Probably round.

Have space between them.

Do not touch.

Held together by { cohesion between like molecules;
adhesion between unlike molecules;
gravitation between all.

Solids result when these forces are *strong*.

Liquids, when these forces are weakened.

Gases, when cohesion and adhesion seem to disappear.

That molecules can move or vibrate in three ways.

That if they move or stop, *work* must make them.

That for work we may get:

Change of place.

Change of shape.

Sound—vibrations.

Heat (vibrations more rapid).

Light (vibrations still more rapid).

Chemical energy (vibrations most rapid).

Electrical }
Magnetic } arrangement of molecules.

That if we exchange work for one of these, we can not have as much of another.

That all molecules *are in motion* in the space around them, for we know of nothing which is not in one or the other of the above states.

Which way do you suppose they vibrate or swing? (Back and forth, up and down, or round and round.)

How about the space *moving* molecules would occupy compared with that when still? (More.)

If we increase the swing still more? (Size would increase.)

There were three forces concerned in holding the molecules together, and there is one especially active in overcoming cohesion, adhesion, and even seemingly of gravitation, with which we will experiment to-morrow.

Lesson 18.—The effects of heat.

Experiment 20.—A thing gives sound or is hot because its molecules have been made to vibrate.

Heat a copper rod: does it grow longer?

Heat a brass ball: does it become larger?

This is called expansion.

Do you see why the molecules take up more room?

Suggestions as to apparatus for Ex. 21: Use the *dry* flask and its rubber cork with a 30 cm. glass tube inserted for the "air bulb." Fill it then with water to test the expansion of a liquid. The pulse glass is filled with colored ether and *vapor* of ether, which quickly responds to the heat of the hand.

Be sure the flask is dry on the outside before heating, or a drop of cold water running down on the hot glass may crack it.

Experiment 21.—1. Make an air bulb of your glass flask, cork, and 30 cm. tube. Dip the lower end of the tube in colored water before putting in the cork, to make an index.

Hold the cool flask in your hands, and see if the inclosed air *expands*. Set the flask in cool water. (What?)

2. Fill the flask full of water, put in a pinch of sawdust, and insert the cork and tube tightly. The water will rise in the tube. Mark the level with a thread. Wipe *dry* on the outside, and, heating gently in the alcohol flame or hot water, carefully observe.

Does water expand when heated?

Dip the flask in cold water—?

Why does a "pulse glass" flow from the bulb in your hand?

Do all the things you have tried expand when heated?

What when cooled?

Prove this with a thermometer by warming and cooling.

Do heat vibrations seem to drive molecules apart?

Read notes on how you proved this with a copper rod.

Read about the ball and ring. (See some Physics.)

How does a gas like air behave?

How a vapor like ether?

How a liquid like water?

Explain the action of a "thermometer." (Heat measure.)

(Both glass bulb and mercury are expanded, but while the expanded bulb would hold more mercury and the column *fall*, the liquid mercury expands so much faster as to make up for all that and more, hence *rises*. All this is reversed when the thermometer is cooled.)

Did any of you observe the column of water in the tube *fall* when you first heated the flask? It did, and I want you to see and explain it.

How about the *sawdust* ?

Write these questions to answer to-morrow :

1. What state of molecules is perhaps represented by swarming bees ?
2. Why can we weld *hot* iron and not cold ?
3. Why does Washington Monument *nod* each day ?
4. Why must great iron tubes be free to move at one end ?
5. Why do the uniting straps of railroad rails have *oblong* holes ?
6. Why do iron gates stick in the summer ?
7. Why does the blacksmith heat wagon tires before putting on ?
8. Why do the gas and smoke from a fire rise ?
9. Give one of the reasons why a full kettle of water overflows when heated.
10. What is one reason for the flow of ocean currents ?
11. Why can warm air hold more vapor of water than cold air ?

Lesson 19.—Who has ever seen bees swarming ?

Samuel, you may tell us how they looked. (Air filled with a cloud of swiftly moving bees.)

Did you see them hived ? (Yes ; they settled in a bunch about as big as a hat, and the man shook them off into a hive.)

Mary may tell me what state of the molecules the bees represent. (When heat sets them vibrating they are like the swarm ; when cooled, like the cluster.)

Thomas, how about welding iron ? (The cold molecules are not close enough to cohere, but when set vibrating by heat, aided by the hammering, they swing near enough for cohesion to act.)

Inside the Washington Monument a heavy weight was hung from the top, its tip resting in the smooth surface of some dry sand. When kept from currents of air it

was found the weight traced a small oblong figure in the sand each day.

What made it ? (Kate : "The sun shone first on the southeast corner, and, expanding the stone more than on the shaded sides, the top was thrown a little to the north-west. When the sun was in the south, the top nodded north. As the afternoon came on the southwest became expanded, and the top was moved northeast ; during the night it came back into position again.")

The iron tubes ? (John : "Grow longer during the heat of day or summer, and shorter at night and in winter ; and the bolts would break if chance was not given for this movement.")

Strap irons on the railroad ? (Jane : "The rails lengthen and shorten, and would break the bolts or straps if a chance to *slip* was not given.")

Henry, does this have anything to do with the rails having a space at one or both ends ? (Same reason ; the track would bend up or to one side in a hot day, if space to expand was not provided.)

Who has observed about iron gates ? (Susie : "Ours sticks so that I have had to climb the fence.")

Well done for a girl !

Why did it stick ? (The molecules of iron must have been flying about on that hot day, and took so much room that the gate was too big.)

Alice : "Our *wooden* gate sticks when it rains. Is it for the same reason ?" (Samuel : "No ; it *swells*.") (Henry : "I think adhesion makes the water get in between the cracks of the wood.")

That is well said, Henry.

Who has ever seen a wagon tire set ? (Robert : "The smith put the four tires together on the ground, piled sticks and corncobs around the circle, and set them on fire. The wheel was laid down on a wooden frame, and when the tires were real hot two men took one with

tongs and slipped it on the wheel. The wood of the wheel began to burn, so they quickly slipped the wheel on a pin over a trough of water and whirled it round a few times. Then the other wheels were done in the same way, and the smith said they were 'shrunk on so tight they would *never* come off.'")

Well told; but now explain *why*. (Ann: "The cobs made the molecules separate, and the iron hoop got so large that it slipped on easily, and when cooled in the water the molecules came nearer to each other again and squeezed the wheel tightly.")

Why do the smoke and gas from a fire *rise*? (Paul: "You told us in the pebble lessons that warm air is lighter, and I think the reason is that it is like a swarm of bees.")

John asks, "But why does it *rise*?"

A good question, John, and one I think the class can understand and answer too. We will all try some experiments to think over for to-morrow's answer to this question.

Experiment 22.—Why a cork *floats* and hot air *rises*.

Fill your graduates to the 30 c. c. mark.

Drop in a large marble or piece of stone. Read graduate and record.

Drop in a dry cork, and read how much the water rises.

Push the cork below the surface by a wire or pencil point, and read again.

Take away the wire or pencil. What does the cork do? The water?

A balloon in the air would be like this cork in water.

Do these experiments help you in answering the questions?

Lesson 20.—Now for our questions. Let us put the results of yesterday's experiments on the board.

Samuel: "Graduate at 30 c. c. + marble = 34 c. c. = rise of 4 c. c."

Kate: "Graduate at 34 c. c. + cork = 36 c. c. = rise of 2 c. c."

Thomas: "Graduate at 36 c. c. + cork *all* under = 42 c. c. = rise of 6 c. c."

Paul: "Removed pressure on cork." (Cork rose and water fell to 37 c. c.)

Who will tell me what this means? (Probably none.)

Has water weight? (Yes.)

Has cork weight? (Yes.)

One c. c. of water weighs—? (1 gramme.)

When the weight of the cork rests on the water, what happens? (Water rises.)

See this scale. I put 5 grammes in this pan, and it *falls*. How much must I put in the other pan to balance it? (An equal weight.)

Now, the water is a wonderfully exact scale and weight combined.

In every case yesterday, as the cork or stone went *down*, the water—? (Rose.)

As the cork rose above the surface, the water—? (Fell.)

As the cork pressed down upon the water the water rose till it *balanced* the cork. What weight of water would do that? (Equal to the cork.)

How can I get the cork to lift *more* than its weight of water? (By pressing on it.)

Yes, the cork raised 2 grammes of water, and by pushing I can make it raise 8. Now, if 2 grammes of water can hold the cork still, what will 8 grammes pushing on it do? (Make it rise.)

How high? (Till 6 c. c. have risen out of the water.)

Then a submerged thing that is lighter than the air or liquid it is in rises because—? (It is pushed *up* harder than it can press down.)

There is much more I should like to teach you about this, but it will come in better at another time (Step

XXXVII, etc.). Let us think first of the water and sawdust in Ex. 21. Before heating, the sawdust in the water was *still*. You heated the bottom of the flask and the water next to it first. The heat made this water——? (Expand.)

Was the expanded water lighter or heavier than the cool layers above it? (Lighter.)

Now, do you see how like the submerged cork it was? The greater weight of the water above obliged the heated water to——? (Rise.)

And as it rose the cold water——? (Fell.)

Why did I have you drop sawdust in? (So that we could see this rising and falling.)

Now for our heated air. The air next the warm water (see § 16, Step XV) became heated. This caused the molecules to vibrate and take up more room, and we say the air——? (Expands.)

Above was the cold air, so what *had* to happen? (Warm air rose, and the cold air flowed in.)

What did we call these inflowing currents? (Winds.)

Air mixed with vapor is also light (see Barometer, Step XV). What will it do? (Rise.)

The heated air from fires, etc.——? (Rises.)

Is this point clear? If so, we will go on.

Why does a kettle full of cold water overflow when heated? (Water expands.)

What is *one* reason for the flow of ocean currents (show map of Gulf Stream, etc.)? (Same as water in flask. The oceans under the continual heat of the tropics become heated on top, and are not able to balance the cold waters on either side, which, pressing under, compel the warm water to flow off.)

Why can heated air hold more vapor than cooled air (see § 16, Step XV)? (Is like the unsqueezed sponge, with larger spaces between the molecules for the vapor to get into.)

So much for the way *heat* overcomes cohesion, etc., and by separating the molecules makes solids, liquids, and gases *expand*. Let us to-day see what happens when we heat a solid still more.

Experiment 23.—Heat a piece of *solid* ice in a spoon. What?

Heat the *liquid* water still more. What?

Light a bit of candle, and write the history of what happens as the solid tallow melts to liquid, etc.

Lesson 21.—A solid when heated first? (Expands.)

If heated still more, till the molecules vibrate very fast and far? (Melts.)

Still more vibration? (Vaporizes.)

What forces had the heat to overcome in expanding a solid? (Cohesion and gravitation.)

In melting ice? (Cohesion.)

In vaporizing water? (Cohesion—of water; adhesion—to dish; and gravitation—push away the air.)

How can I stop these vibrations and get back my ice again? (Cooling.)

What is "cold"? (Simply *loss* of motion of heat.)

If, then, I bring something whose molecules are moving but little, near or in contact with another object whose molecules are in rapid motion, what will happen? (The molecules of the hot thing will give of their motion to the cool thing till both are equal.)

The old law of loss and gain! To heat one thing, another must—? (Cool.)

To cool an object—? (Another must warm.)

Now, about the candle? Jane, you may read your notes. ("I lit the candle. The heat melted the solid tallow into a liquid, and this rose up the wick, and, heated still more, became a gas, which burned with a flame.")

I can not explain all this to you now, but some day you will learn how heat vibrations first expand, then melt, then vaporize, and, last of all, tear the little mole-

cules into the still smaller atoms we have talked of. No "cooling" can then ever give us back our molecule again, any more than we can get back tallow or wax by cooling the gas and vapor that rise from the candle.

But the heat of the flame did not *touch* the ice or water, and to show how its motion was passed by the spoon from flame to ice, let us try some experiments.

Experiment 24.—To explain how the heat of the flame could do this *through* the spoon, place five or more equal-sized marbles in the groove of a level piece of flooring, and when all touch, gently tap one end of the row and note what happens. Do this five times. Write what you saw. How does this help you to understand the way the heat got through the spoon, or the sound from a bell to your ear?

Experiment 25.—Take a long slate pencil, and rods as nearly as possible of equal size and length, of iron, copper, and wood. Place pieces of wax or tallow the size of a No. 5 shot equally distant from one end of each. Now, in turn, hold one cm. of this end of each in the same part of a lamp or gas flame, and record the time it takes to melt the wax or tallow, up to three minutes. Do all things carry heat equally fast? Which the poorest of all?

Lesson 22.—What happened when you tapped the end of the row of marbles? (All stayed still except the last one, which was thrown off.)

Why was this? (The pencil struck the first one a blow, which it passed to the next, that one to the next, and so on till the last one, having nothing to hold it back, flew off.)

How does this illustrate the passage of the heat vibrations through the spoon? (The blows of the flame were given up to the spoon; then the molecules of the spoon passed them along till they in turn gave them up to the ice, and the ice molecules were set swinging so violently

as to get beyond the control of cohesion, and, slipping apart, became liquid water.)

How were the vibrations of the bell brought to the ear? (The bell set the molecules of air next it to swinging, these passed the blow to those next, and so on till the last ones struck the ear, and we "heard.")

James may read his notes about the rods. ("Took an iron nail, copper rod, slate pencil, and wood skewer. Got the ends even, and made a mark across them all 6 cm. from the even ends. On each mark laid a small piece of wax, and kept time while I held the ends successively in the flame. Iron nail carried heat, and wax began to melt in 20 seconds. Copper rod carried heat, and wax began to melt in 15 seconds. Slate pencil carried heat, and wax began to melt in 90 seconds. Wood began to burn, and burned to the wax in 165 seconds.")

Very good.

Do all things carry heat equally well? (No.)

Which the best? (Metals.)

Which the poorest? (Wood.)

What do the poorest conductors do? (Take fire.)

Which seem to "pass the knock along" the most easily? (Metals.)

Why do wood and other things that burn conduct the vibrations so poorly? (Have holes and breaks between the molecules, which the vibrations can not cross.)

Should you think *liquids* would conduct heat well? (No; the spaces between the molecules are large.)

This is truly the case, and we find it very hard to heat liquids from the *top* downward. When heated at the bottom what happens? (Rising and falling currents are set up, as in the flask.)

How will air and gases heat? (Poorest of all, as the molecules are so widely separated.)

How our study of molecules helps us to explain

things! Best of all, it will be the key to *very* much that is to follow.

There is still another question about them. When they separate through heat or draw together through its loss, is it with *much* or *little force*? I will give you some things to think over for to-morrow.

1. Remember Washington's Monument *nods*.

2. Remember how huge iron tubes (bridges like that over the St. Lawrence at Montreal, or across the Straits of Menai) have the ends on rollers, and at times move several feet in a day.

3. Remember the oval holes in railroad rails.

4. Brooklyn Bridge is said to rise and fall at the center several feet each day.

5. A building in Paris had a very heavy roof, and the walls began to spread. It was brought into place by running huge iron rods through from one side to the other. Each had a thread and nut on one end, and every *other* one had a row of gas jets under it. How did the men manage?

Lesson 23.—Samuel, what makes the Brooklyn Bridge rise and fall at the center? ("The heat of day expands the cables, and the center drops; during the night the cables contract, and the center rises.")

Jane, is it much work to raise and lower this bridge? ("Much.")

John may tell me about the Paris building. ("The gas was turned on, and expanded the alternate rods, which were screwed up tight while hot, and on cooling contracted and drew the walls together a little. The other set of rods thus became loose, and were screwed up. This was repeated as often as required.")

Was much power shown? ("Very much.")

Robert may tell me what he thinks of the monument. (The expansive force to lift half that column of stone must be *immense*.)

Mary, tell me about the bridge ends. ("Great power needed to move such masses of iron.")

James may speak of the rails. ("If chance were not given for the ends to move, the rails would warp up or sidewise, showing *tremendous* power.")

There seems to be no doubt but this motion of the molecules is made with enormous force—a force able to do almost anything, and wholly beyond *our* power to stop. Now comes our *last* experiment.

Experiment 26.—Take a cold glass marble and suddenly heat it in a hot flame or fire. Record and explain what happens. Now drop a marble whose molecules are in rapid vibration in cold water. Record and explain.

Who can picture the molecules of the hot marble to me? (A mass of violently moving parts.)

Is glass a good conductor of heat? (No; for we held 8 cm. bits in a flame till the middle softened enough to bend.)

Suppose this violently moving mass, in its expanded condition, *suddenly* has the outside cooled by dropping in water? (The outside would suddenly contract over the expanded interior, and, being *too small* to fit it, would have to break.)

Why would not an iron ball do the same? (One reason would be that such a good conductor of heat vibrations could not be *suddenly* enough stopped.)

Who will explain the chipping off of a suddenly heated marble? (The outside tried to expand before the cool inside could follow, and they had to separate.)

Why do lamp chimneys often break when placed over a very hot flame? (Inside expands too quickly.)

Why break from a draught or spatter of water? (Outside contracts over the hot inside.)

Why does hard coal snap so when put on a hot fire? (Same as cold marble.)

Indians used to cook in pails of birch bark by heating

stones and dropping them in among the meat. How did it affect the stones? (Cracked.)

This brings us pretty close to the answer of the question we started with.

What is another way (besides *roots* and *frost*) sharp stones might be made?

How many have enjoyed asking Nature questions?

Your gain in *knowledge* has been far beyond what you can now realize. But, interesting and helpful as it has been, we shall all enjoy a change.

Review.—But little is needed, as this work will all come up again in new relations, and the work being done by the pupil will be a part of his *personal experience*, and not easily forgotten.

Should time permit, the following will be profitable:

1. Each one tell me something he has particularly noticed in these lessons. (Go round the class as hands are raised, but see that the dull and less interested ones get a *first chance* and a frequent one. The bright pupils can afford to keep still. No one must *repeat* what another has told, but may always add to or modify if he deems it desirable. See reviews in previous lessons.)

2. Has any one a question to ask or subject he wishes more light on? (Let them understand that good questions show thought and care, and are much to the *credit* of the asker.)

If marking *must* be done, let it include four things:

Character of *work* in experimenting.

Concise and yet full *notes*.

Neatness in notes and in experimenting.

General *grasp* of the subject.

Material and **apparatus** should now be put away, clean and ready for the next class.

Next step along this line, XXXVI—Crystals.

STEP XXXII.—MAN.

The object of this step is to show how man, the highest animal, adapts himself to the varied conditions of his environment. How "want" has been "the mother of invention." This will continue the idea of Animals in Winter Quarters (Step XXIX), and that of Plant Relationship (Step XXVIII). To aid in other ways, the races and distribution of man are observed, and the work so arranged as to present to the child general ideas regarding the evolution of modern civilized life.

The time of the year will fall in late spring, and about forty lessons of half an hour each will be sufficient. In order to bring so ambitious a subject within such limits, it must be clearly kept in mind that this stage of the work is *suggestive* rather than *exhaustive*, and each topic must be briefly and energetically treated and then promptly dropped for the next. Presented thus, the pupil has his eyes opened to new relations of things, and is left with that awakened interest which desires to know more.

Equipment.—A good globe and a large map of the world, with books to which the pupils can have access for information. Pictures of man in the various surroundings of differing climate; specimens and models of dress, food, manufactures, dwellings, etc., will also help, and may little by little form a very interesting collection for the school.

The map must be hung low enough so that pupils can reach all parts of it. A good way is to have a large outline made on a low, soft pine blackboard. Color each

portion of the land with that of the race of man found there (red, black, yellow, brown, and white), as given in some physical geography. These colors will stand for the race, and the principal divisions of land can be named in small lettering on the margin. On this, as the work proceeds, can be affixed, by small tacks or short, strong pins, the models, drawings, pictures, or samples of food, etc., each in its proper locality. This map should be easily accessible to the pupils during school hours, and will grow in interest as the work proceeds, presenting a bird's-eye view of the whole at the end.

Preparation of the Teacher.—Go through the lessons carefully, using such books of reference as your pupils will have, and in the spirit of a child travel the road you are to lead them over, that all stumbling may be warned against, and hesitation on your part be avoided.

The most helpful books at my command have been Tylor's *Anthropology*; Tylor's *Early History of Mankind*; Wood's *Natural History—Man*, Vols. I and II; *Riverside Natural History*, Vol. V; Drummond's *Ascent of Man*.

Arrange for each pupil to have a notebook about eight inches wide.

The Lessons Introduced.—What traveling animal was omitted from our study of migration and hibernation? (Man.)

In observing the relationships of plants, what important one was in great measure left out? (That to man.)

A famous poet has said, "The proper study of mankind is man," and it is to consider our own most important position in the world of Nature that we shall pursue this step.

How many zones (or climates) do maps show? (Frigid, temperate, torrid.)*

* Teacher explain each of these terms.

In which season of the year can our native animals and birds live the most easily ? (Summer.)

Which of the earth's zones is most like summer ? (Torrid.)

Men who have studied about the matter find that man has not always been as comfortable nor had so many things to do with as we, but that there was a time when he was wild and savage, living on fruits and roots, and with perhaps not even a shelter at night.

In which climate could such people live ? (Tropical.)

Now, in our study of how mankind gradually improved on this wild state of the tropics, and became what we see about us to-day, we will follow this **plan**.

1. **Take color** as a convenient method of classifying the differing races of man (as on this blackboard map of the world).

2. **Starting with the wild man** of the tropics, we will consider **what he had**, and then, as he migrated to other climates, **how he adapted his life** to the new surroundings.

3. That we may more clearly trace the steps of progress, we will take the following topics, each by itself: Food, weapons, fire, utensils, conveyance, buildings, language, permanent expression.

Before taking up these topics, one question needs thought, **Why should tropical man migrate?** With fruits and roots to live upon, and so little need of clothing and shelter, why go to other places where life is frequently more difficult to maintain ? Why do animals migrate ? Why do our native birds disappear before the English sparrow ? Why are the Indians not found in the eastern United States ? Why did the white man come to America ? Why do trappers brave the dangers of Hudson's Bay, and whalers the icy seas of the north ? Why do bees swarm ?

THE LESSONS.

Before each topic let the teacher instruct the pupils where to look for such information as shall supplement that which their previous reading, geography, and history has supplied.

The study of such charts as Guyot gives in his Physical Geography, or the pictures in Frye's Complete Geography, will be very helpful. Accustom them to take brief notes of what they find, and where.

Now, with a large map before the class, and notebooks in hand to briefly record what is said, all is ready.

Food.

Let us rule our notebooks into three portions, the left-hand and middle ones twice the width of the right-hand one. Head the left-hand column "Food," the middle column "People and Place," the right-hand column "Authority."

Wild people are much like animals, roving about with no real home. Who has found out about such a people? (Indians of Brazil.) Write that in the middle column. Where did you find the references? (T., 206 to 214.) *

Place that in the right-hand column under "Authority."

What does Mr. Tylor say they eat? (Wild fruits, roots, reptiles, etc.)

Write these in the left-hand column.

What seems the first advance in this matter over the wild beasts? (Tool making, such as hooks and nets to catch fish, and traps for animals.)

* In what follows, "T." stands for Tylor's Anthropology; "T. E." for Tylor's Early History of Mankind; "N. H." for Riverside Natural History, Vol. V; "W. I" (or II) for Wood's Natural History of Man, Vol. I (or Vol. II).

Can you name a people living where such food is apt to fail? (Indians of North America, N. H., 148 and 155.)

Your authority? (Hiawatha's fasting.)

How did they provide? (Raised corn, etc.)

This would be the beginning of what important industry? (Agriculture.)

Have you found any people which differ from either of these given? (Tunguz (pronounced Tungooz) of north-eastern Asia, T., 219, 220.)

These live how? (By the flesh and milk of domesticated animals.)

What advance can be made on either of these? (The union of agriculture and herding, as in Genesis xxvi, 12-14, and the tribes of northern Europe, T., 220.)

How is food obtained to-day? (Through the medium of commerce, whereby each can have the produce of all the earth, and where the want of one country is supplied by the surplus of others.)

The pupils' notebooks should now present an appearance somewhat like the following:

FOOD.	PEOPLE AND PLACE.	AUTHORITY.
Wild fruits, roots, reptiles, eggs, honey, game, and fish.	Red Indians of Brazil, South America.	Tylor, 206-214.
Add cultivated corn, etc.	Red Indians of North America.	Longfellow's Hiawatha; N. H., 155.
Flesh and milk of domestic animals.	Tunguz of north-eastern Asia.	Tylor, 219, 220; N.
Agriculture and herds.	Isaac and patriarchs. Old tribes of northern Europe.	Bible, Genesis xxvi, 12-14; T., 220.
Commerce. Want of one place supplied by surplus of others.	All nations and tribes.	

It will at once occur to the teacher that the above is very brief and incomplete; but it introduces the matter to the child's notice, and if the lessons are to be kept fresh and bright much time can not be given to each point. Moreover, the subject of food will be continually appearing incident to the consideration of other topics; hence would *promptly* pass to the next subject. Again, in advance, instruct the class what to read about, and where.

Tools and Weapons.

In getting food we have already observed the need man had for various aids. The way these grew out of his needs is one of the most interesting chapters of human history.

We do not know of any race of men who are in the first stages of tool making, and so let us try to *imagine* what they could have found to use. (Sticks—round or sharp—stones, thorns.)

The first could be used to——? (Strike, push, or throw.)

The second could be used to——? (Throw or pound.)

The third (sharp stones) to——? (Cut, hack, scrape, saw, rasp.)

With the fourth (thorn, bone splinter, flake, etc.)? (Make holes to sew, etc.)

Having noted these in your books, let us trace how the inventiveness of man has developed the numerous tools of to-day.

The Stick to Strike.—Have you found any peoples using it? (Fiji Islanders; N. H., 67, 68, and T., 184.)

Yes, and *all* peoples use the stick to kill a snake.

What improvement has there been? (Carved, ornamented, and set with sharp teeth and bits of bone or teeth by the Fiji Islanders, or set with sharp flakes of stone by the American Indians.)

These made terrible weapons to fight with.

If the branch or club were flattened to an edge it would form——? (Wooden sword; of Nootka Sound Indians, N. H., 138.)

What peaceful use would such broad, flat blades serve in traveling on water? (Paddles; of New Zealanders, W. II, 174.)

If one pointed tooth or stone were set in the club it would make——? (Pick; Eskimos, N. H., 122; T., 187.)

If this pick were flattened to an edge parallel to the handle——? (Axe; T., 189, 190.)

With the handle shortened and blade of metal lengthened——? (Sword.)

What peaceful instruments seem to have grown out of this? (Sickle and scythe; T., 190.)

Returning to the pick and flattening the edge at right angles to the handle, it would be——? (Adze; of the Polynesians, T., 189.)

For what use would these serve in tribes which cultivated crops? (Hoe; of North American Indians, N. H., 165; T., 216.)

The pick made heavier and dragged over the ground it was desired to loosen became the——? (Plow; of Sweden, and used in the Azores to-day, T., 217.)

Stick to Push with.—Finding that it was an advantage to have the end pointed, man first did it by——? (Burning; T., 194.)

What was the next improvement? (Tipped with sharp bit of bone or ivory, by Eskimos, W., II, 706; stone, by North American Indians, W., II, 651; or metal of more recent date, T., 189.)

How would such a spear aid in the search for roots? (To dig; Digger Indians, N. H., 177.)

Made broader, and of metal, this would become the modern——? (Spade; T., 216.)

If the stick had several points (as the Australian fish

spear, N. H., 32) it would naturally lead to the——? (Fork, still used in the Azores.)

Shorter and smaller, this would become the table fork.

The stick to throw is used by all tribes (as Kaffir, W., I, 108).

Curved and flat, it becomes the——? (Boomerang of Australia; N. H., 33.)

When long and pointed, it became—— (The assagai of South Africa; W., I, 103.)

Lighter spears would form the——? (Arrow.)

Where the bow originated is unknown (T., 195).

The smooth stone would first be used for a missile, as when any one "throws stones" (W., II, 41). This use early gave rise to the sling, which gave the stone a higher speed (T., 193, 194). Held in the hand, the stone formed the first hammer (T., 184, W. I., 98).

What improvement would relate it to the axe? (Adding a handle.)

What need arose as man began to use grain for food? (To crush the seeds for bread making.)

What was the earliest mill? (Mortar and pestle of stone, as of California Indians; N. H., 212, and T., 200.)

Improved, this became the "metate" of the Mexicans (T., 201; N. H., 195). Just how this crushing by a roller changed to the crushing by one stone revolving on another is not known, but such hand mills have been used from the earliest historic time to the present (is now used in the Azores), and was the pattern of our modern mills.

The sharp stone had many uses. As a cutting tool it was used to skin and cut up game, prepare garments of skins, make weapons, etc. (T., 186). These flakes have already been noticed in connection with the club, etc. With rounded but sharp edge, it formed the "scraper" for dressing skins, etc. (T., 187).

If heavier and with broad edge, it could be used to hack (T., 188).

What modern kitchen tool is on the same plan? (Chopping knife.)

A long flake with jagged edge might be used as a saw (T., 192), and this improved, made of metal, and supplied with a handle, became the hand saw of to-day.

From what might the rasp and file have originated? (Stone with rough surface.)

The pointed stone, thorn, or tooth would have served what additional purpose? (Awl; T., 187.)

The holes having been made in the skin garment or boat, what need would then arise? (Needle; of the Eskimos, etc., N. H., 120.)

Where holes were to be made in hard substances, like stone, the drill was used (T., 202).

What were the steps leading to the drill of to-day? (1, a pointed tool revolved between the hands; 2, the cord or thong rapidly wound and unwound by a helper; 3, the cord was fastened to a bow, so that one man could work it; 4, when the drill was fastened to a crooked stick the continuous motion of the modern "brace" or "bit stock" was foreshadowed.)

(For much regarding this, see Tylor's *Early History of Mankind*, pp. 190 and 241-248.)

A return to such primitive methods is seen in the modern sawing of stone by soft iron blades armed with sand, and in the diamond drill of the miner, or emery and diamond dust of the lapidary.

Notebooks.—These should show a brief record of the subject, as under food. If the **drawing** work of the pupils could also illustrate such notes, an exceedingly valuable record would result, especially as the years passed and the ingenuity and mechanical skill of class after class resulted in a **muséum** well supplied with **models**.

Fire.

Mankind having selected his food, and by various tools secured it, another desirable step would be some method of cooking. For this fire is needed.

For the legends and myths of savages, as to how they first secured fire, see Longfellow's *Hiawatha* and Tylor's *Early History of Mankind*, p. 233, ff.

What was the probable way? (Lightning or the volcano; T., 260.)

How would man first keep such fire when traveling? (Carry it along.)

When by accident it was lost, how then?*

Having illustrated one way, I shall now simply give the data in notebook form:

FIRE.	PEOPLE AND PLACE.	AUTHORITY.
Myths regarding origin.	Ojibway Indians of North America. Polynesia.	Longfellow, in <i>Hiawatha</i> (The Peace Pipe); T. E., 233.
Probable origin. Lightning and volcano. How spread and kept.	All	T., 260.
Carried and cared for. Ways of getting if lost.	Australians	N. H., 30.
Friction—stick and groove.	Polynesian Islands	T., 261; N. H., 30.
Fire stick.....	Australian.....	T. E., 239 ff.
Fire drill.....	Greenlanders	T. E., 244-248.
Fire drill—bow....	Chukchees, north-eastern Asia.	Voyage of the <i>Vega</i> , 312 (Nordenskjöld)

* In this same manner draw out the pupils after they have had the chance to inform themselves. Just *how* this will be done will differ with each teacher and class.

FIRE.	PEOPLE AND PLACE.	AUTHORITY.
Pyrites and flint— tinder.	Fuegians, South America.	T. E., 249.
Flint and steel—tin- der.	Ancient civilized peoples.	T., 263.
Mirrors (concave)...	Peruvians (?), South America.	T. E., 252, 253.
Burning lens.....	Greeks, southern Europe.	T. E., 251.
Friction match.....	World of to-day.	

Utensils and Cooking.

Fire having been secured, the next step will be to trace the methods of cooking, and the dishes, etc., connected with the process.

MODES OF COOKING.	PEOPLE AND PLACE.	AUTHORITY.
Raw food.....	Australians.....	T., 264.
Raw food.....	Eskimos, North America.	T., 265.
Roast or broil by fire.	Ancient Greeks. Greece.	T., 266.
Roast on spit to turn.	Savage peoples to recent times.	W., II, 578.
Bake in the ashes ..	Micronesians, Pa- cific Islands.	N. H., 74.
Bake in hot pit.....	Madagascar Island.	T. E., 263.
Bake with hot stones	Society Islands, Pa- cific Ocean.	N. H., 85 ; T., 267.
Clay oven.....	Biblical and Oriental	Bible Dict.; T. E., 263.
Brick oven.....	Old colonial days.	
Iron range.....	Modern.	

These seem the steps by which the modern modes of roasting and baking have been evolved. *Boiling* seems to have been a later device to cook food which could not

well be roasted, and the interest in this mode of cooking is increased when we consider that it was the origin of all of our beautiful pottery. * The steps by which baking led to boiling seems to have been as follows :

MODES OF COOKING.	PEOPLE AND PLACE.	AUTHORITY.
Boiling by hot stones in a hole.	Australian	T. E., 267.
Boiling by hot stones in a skin.	Assiniboin Indians, North America.	T. E., 265 ; T., 266.
Boiling by hot stones in a basket.	Indians, North America.	T., 266 ; T. E., 266.
Boiling by hot stones in wooden bowls.	Kamtschatdales, Kamchatka.	T. E., 267, 268 ; T., 266.
Baskets and bark kettles over fire.	Indians, North America.	T. E., 271.
Stone vessels.	Eskimos, Greenland.	T. E., 272.
Baskets plastered with clay to prevent burning.	Indians of North America.	T. E., 274-276 ; N. H., 158.
Gourds plastered with clay to prevent burning.	Indians of southeastern North America.	T. E., 274 ; T., 274.
Wooden bowls plastered with clay.	Indians, South America.	T. E., 273 ; T., 274.
Earthen pot (porous ware).	Kaffir, South Africa.	W., I, 233.
Earthen pot varnished.	Peruvian Indians, Peru.	T. E., 274 ; T., 276 ; N. H., 239.
Earthen pot glazed.	Chinese, China.	T., 276.
Copper dishes.	Indians of North America.	T., 278.
Iron kettles, etc.	Civilized nations of to-day.	

* See Tylor, *Early History of Mankind*, pp. 265-273.

Modes of Travel and Transportation.

How man got from place to place and carried his things may next be considered.

By drawing out the difficulties of land travel in a new country without roads or bridges, lead the class to appreciate the reason why tribes and peoples have always settled along rivers and by the sea. The early occupation of America by Europeans may well illustrate this, especially the French settlements on the "portages" connecting river systems, such as those between the Great Lakes and the Ohio or Mississippi.

While much of interest might be found in the development of land travel, it is believed that water travel is more typical, and will illustrate the point sufficiently. Introduce the subject, and assign reading, as before. Thus, in a thoughtful discussion with the class, draw out the subject in its natural sequence. Especially try to have the class see how *want* has been the motive, the material at hand has determined the method, and how one thing has gradually led to another.

MODE OF TRAVEL.	PEOPLE AND COUNTRY.	AUTHORITY.
Log or branch . . . . .	.....	T., 252.
Inflated bladders or skins.	.....	T., 255.
Raft of rushes	South American Indians, Lake Titicaca.	Knox, Boy Travelers, 207.
Raft of logs	Indians, South America.	T., 255.
Log and outrigger..	Fijians, Fiji.....	T., 255.
Dug-out.....	Andaman Islands, Bay of Bengal.	W., II, 213, 214.
Dug-out and outrigger.	Polynesians.....	T., 256; N. H., 49, 86.

MODE OF TRAVEL.	PEOPLE AND COUNTRY.	AUTHORITY.
Canoe of bark.....	Indians, North America. Australians.	W., II, 690; T., 254; W., II, 103.
Canoe of skin.....	Eskimos, Greenland.	T., 254; N. H., 116.
Canoe of boards (sewed).	Melanesians.....	T., 255; N. H., 59, 60.
Boat with nailed boards.	Egypt, northern Africa.	T., 257-259.
Ship.....	Spanish, etc.	
Steamer.....	United States, North America.	

This seems as far as it is advisable to go, although it would be highly interesting to trace the development of the means of propulsion from the hand to the modern screw propeller.

We next study the development of **shelter** from the elements and protection from enemies.

A consideration of clothing is omitted, as it would lead to embarrassing questions in a mixed school.

Two factors have been potent in this: **the need** and **the available materials** with which it could be supplied.

What will man need shelter from in the tropics? (Rain, sun, and danger from animals or other men.)

What additional in other parts of the earth? (Cold.)

This subject will work out somewhat like the following:

Shelter and Protection.

REGION AND MODE.	PEOPLE AND COUNTRY.	AUTHORITY.
<i>Tropical Forests.</i>		
Screen of leaves or branches	{ Indians of Amazon, South America.	} T., 230.
Circular hut of leaves, etc..		
Huts in trees to escape water	Indians of the Orinoco, South America.	W., II, 633-636.

Shelter and Protection (continued).

REGION AND MODE.	PEOPLE AND COUNTRY.	AUTHORITY.
<i>Tropical Forests.</i>		
Hut on piles (for protection)	Dyaks of Borneo....	W., II, 498, 499.
	Swiss lake dwellers..	N. H., 464.
<i>Forests of Temperate Climate.</i>		
Bush shelter	Bushmen of South Africa.	W., I, 274.
Screen of boughs or grass ..	Australian	T., 230.
Circular hut	Bushmen of South Africa.	W., I, 275.
Bark hut	Indians of North America.	T., 231.
Hut plastered with clay....	Lake dwellers of Switzerland.	T., 230-234 ; W., II, 861.
Square or oblong house....	Iroquois Indians, North America.	N. H., 166 ; T., 232.
Log house.....	Early civilized settlers in dangerous times.	
Frame house.....	Modern times of peace	
<i>Treeless Plains of Temperate Climate.</i>		
Tent of bark or skins	Patagonians of South America.	N. H., 261 ; W., II, 539.
Tent of cloth.....	Tartar tribes, Asia...	T., 231.
Dug-out and tent roof.....	European peasants (ancient).	T., 231.
<i>Rocky Districts.</i>		
Caves.....	Prehistoric savages of Europe.	T., 229, 230.
Rough stone screen.....	Australian.....	T., 232.
Cliff cavern for security....	Cliff dwellers, New Mexico.	N. H., 185.

Shelter and Protection (continued).

REGION AND MODE.	PEOPLE AND COUNTRY.	AUTHORITY.
<i>Rocky Districts.</i>		
Rough stone house	Azores of to-day. Hebrides.	T., 232.
Hewn stone	Egypt and Mexico (ancient).	T., 233; N. H., 198-204.
<i>Arctic Climate.</i>		
Snow or ice igloo	Eskimos, North Amer- ica and Greenland.	N. H., 118, 119.
Skin tent (double)	Chukchees, northern Asia.	The Voyage of the Vega, 288-290; N. H., 441.

The evolution of the *brick* in countries having a very dry climate is set forth in Tylor, pp. 233, 234; although the *original* suggestion would seem to have been the blocks of mud, which naturally form by cracking when the bottom of ponds or rivers is exposed to long-continued drought (Nile and Euphrates).

Language.

The progressive steps are so well illustrated by the child from infancy to youth that I simply refer to two good authorities: Tylor's *Anthropology*, chapter iv, and Drummond's *Ascent of Man*, chapter v.

Permanent Expression.

Mankind early felt the need of communicating with the absent or of making a permanent record of thought or important events. How this want has developed into the beautiful books, paintings, and statuary of to-day is exceedingly interesting, and a little time may well be spent in its introduction.

I would suggest the following line of work :

MODE OF EXPRESSION.	PEOPLE AND COUNTRY.	AUTHORITY.
Snake skin and arrows.	Indians in Miles Standish.	Longfellow.
Burned cross.....	Scotch, in Lady of the Lake, Canto III.	Scott.
Picture writing.....	Indians of North America. Modern advertisements.	T., 168.
Picture words.....	Modern rebus	T., 169.
Sound signs	Egyptian and Phœnicians.	T., 176.
Printing	Chinese, etc.....	T., 180.
Illustrated books...	Modern	
Painting in color...	Ancient Egyptian. Modern masters.	T., 303-305.
Sculpture, bulls, etc.	Assyrian (ancient)..	T., 302.
Sculpture, sphinx, etc.....	Egyptian (ancient).	T., 300-302.
Sculpture, Laocoön (myth)	Greece	Bulfinch, Mythology, 281.
Sculpture, Lion of Lucerne (history).	Swiss (modern)....	Plon's Life of Thorwaldsen, 73, 262.

This is as far as it seems wise to go.

Review in connection with daily work in literature, geography, history, etc.

The next step in animal work is XXXVIII—Life Histories.

STEP XXXIII.—COLLECTIONS.

This step in the original plan is omitted, as all needed information can be easily found elsewhere.

STEP XXXIV.—WINTER QUARTERS OF PLANTS.

Object.—To introduce the pupil to a new and interesting phase of plant life; exhibit new relations in a review of former lessons, and give something of the physics and chemistry of plants.

Time.—About thirty half-hour lessons in late autumn. Much of the work will be experimental. In schools without a laboratory it had best come after the other pupils are dismissed.

Material.—Much of this is the same as that of steps which will precede this in time (VI, XII, XIII, etc.), and which it will be economy to use. For a class of thirty provide the following, which have proved satisfactory, or make such substitutions as may be necessary:

30 fleshy taproots—turnip, carrot, beet, or parsnip.

30 multiple roots—asparagus, plantain, or timothy grass.

30 fleshy root stocks—potatoes, Solomon's seal, or May apple.

30 corms—crocus, spring beauty, or gladiolus.

30 coated bulbs—onion or tulip; should be such as will flower.

30 scaly bulbs—lily or oxalis.*

30 sections of endogenous stems—cornstalk—cut between joints.

* These roots, etc., should be small, but well formed and shapely.

30 sections of exogenous stems—oak. See Step XIII.

30 terminal (or large) buds of each of the following: woolly (hickory), varnished (poplar), buried (sumac), flower (hepatica and hazel). See Step IV.

15 "pulse" or "palm" glasses, set in boards and with protecting boxes.

15 thermometers. Milk thermometers best.

15 bright tin cans—one-pound corn or fruit tins.

15 larger tins to hold the small ones—two-pound fruit or tomato cans.

Pieces of variously colored cloth, weighted by shot in the corners.

Starch, gluten, dextrine, sugar, ether, nitric acid, iodine solution.

10 sets of experiment cards, as in Steps XXXI or XLVIII.

Notebooks, one for each pupil, about 4 × 6 inches, opening at the end, and of at least fifty pages of unruled paper.

Preparation of the Teacher.—Work through the step before attempting to give it to a class, trying all the experiments and consulting books till the principles involved are thoroughly grasped. When this has been done and the specimens and apparatus are provided, *go ahead*.

While it is desirable to follow the outline of lessons given as fully as possible, teachers with limited resources need not hesitate to give such part as a solid basis of individual observation and experiment can be provided for.

Do not *tell* much, but omit whatever can not be made a matter of experience or observation to the pupil.

THE LESSONS.

1. A few days before the lessons are to begin ask the children to bring all the things they can find which are typical of autumn, such as colored leaves, fruits, seeds,

roots, etc. With these decorate the schoolroom, and, if desirable, have a public "**parents' day**" or **harvest festival**.

2. While the decorating is going on have the **reading** work center around autumn, its work, sports, and beauties, and winter in its various phases.

3. With this introduction, now begin in regular class work to acquire a more intimate knowledge of these products of the summer, that the reason for it all may later be discovered. Have the **class make** such **drawings** (colored, if time permits) as shall with brief written notes exhibit the form and structure of the following things:*

Taproot, whole and in cross section, to show solid interior.

Multiple root, whole, to show its form.

Root stock, whole and in cross section, showing true roots, buds, and scale leaves.

Corm, whole (showing leaf scars and buds) and in section to show solidity.

Coated bulb, whole (for form and roots) and in vertical and cross sections, to show buds and concentric scales.

Scaly bulb, whole and in both sections, to show loose scales and buds.

Endogenous stem, cross and vertical sections, to show woody fibers.

Exogenous stem, cross and vertical sections, to show rings, pith, and bark.

Woolly bud, whole and in enlarged vertical section.

Varnished bud, whole and in enlarged section.

Buried bud, with the base of the leaf stalk which hid the bud.

* It may be well to test for foods (see 9) at the time the material is in hand; but it distributes the experimenting better to bury bits in sand and delay.

Hepatica bud, to show the hairy leaves protecting the well-advanced flowers.

Hazel twigs, showing long staminate (♂) catkins and rounded (♀) buds, all ready to open early in the spring.

These drawings and notes should be on the upper half of a double page of the notebook, that later observations, etc., may be added without turning a page.

The class having become familiar with these specimens and able to name them correctly, proceed to

4. **Review the conditions of plant life** and growth (see Steps XXIII and XXVIII).

Moisture taken from the earth by— ?

Conveyed to the leaves as needed by— ?

Concentration of crude sap in the— ?

CO₂ decomposed and true sap elaborated by— ?

Sap descending through— ?

5. Then bring the subject before the class by **questions**.

What happens to the delicate root hairs in winter ?

What happens to the leaves ?

To the sap ?

To annuals like our beans, squash, and corn ?

If, then, the feeding organs of trees are destroyed and many plants **killed** entirely, **how can we ever have them again ?**

Expand and impress this query till the class can see that only two ways are open :

A. **By the preservation** of the first (biennials and woody plants).

B. **By the seeds** of the second (annuals).

A. *Preservation.*

6. What is the meaning of the word "preservation" ?

What are the dangers to be guarded against ?

Excessive loss of heat—cold is only *absence* of heat.

Sudden changes in temperature—cold nights and warm days, etc.

Excessive moisture—rain and snow.

Loss of natural moisture sap—by evaporation.

Delay of spring—ability to endure.

Too early growth—before settled warm weather.

7. **Experiments** to prepare for an intelligent discussion of the subject.*

The Effects of Evaporation.

Experiment 1.—Cover the bulb of a thermometer with thin cloth; read and record the temperature; then moisten the cloth with a little ether or alcohol, and holding the thermometer by the upper end, wave it about gently for one minute and read the temperature again.†

Why has the mercury fallen? (**Heat is needed to turn a liquid to vapor.**)

Experiment 2.—Place a drop of ether or alcohol on the hand. How does it feel? Why?

Why does fanning one's self cool the skin? (Hastens the evaporation.)

Why is a breeze cooling? (See Tyndall's Heat, pp. 403-414.)

Water coolers are made in hot, dry countries by filling an unglazed and porous jar with water and hanging it in the wind under a shade.

How does it work? (Rapid evaporation from the sides of the jar.)

Butter may be cooled in dry weather by placing it in a new flower-pot saucer partly filled with water and inverting a new and wet flower pot over it (*in the water*). Why?

* Each pupil should, when possible, try each experiment and record his observations. If this can not be, divide the work among the class, so that the responsibility of *something* will rest on each.

† See 42, Step XIX.

How does perspiration keep us from overheating ? *

Why are wet clothes or feet dangerous to health ? †

How is ice made in warm climates ? ‡

What is the "wet and dry bulb thermometer" of the signal service ?

Experiment 3.—Press the mouth of an "empty" bottle down into some water: why does it not enter ? (Air can not escape.)

Push a dry sponge quickly under water and then remove it. Why has the water not wet it all through ?

Weigh some clean corks.

Immerse quickly, and weigh again.

Why have they gained so little in weight ?

Stuff a wide-mouthed bottle full of cotton, wool, or cork, and add all the water it will hold. Quickly cork and invert. After twenty-four hours observe.

What is in the top of the bottle ? (Air.)

Is the cork, etc., now wet ?

As the air got *out*, the water got— ? (In.)

In succession dip the different kinds of buds in water and record why the water wets them so little.

Immerse an apple. Why does it not become very wet ? (Wax.)

Do the same with an orange. Why not wet ? (Oily.)

What **ways** can you now give **by which a plant keeps out wet** ?

Experiment 4.—Balance a sound, uncut potato by a pared one.

After twenty-four hours' drying, which has lost the most ?

Why ? (Corky covering gone.)

Take two similar sound apples and treat as the potatoes. Why ? (Waxy covering.)

* See 42, Step XIX.

† *Ibid.*

‡ Encyc. Brit., Ice, or Tyndall's Molecular Physics, p. 399.

Do the same with two oranges or lemons. Why? (Oily coat gone.)

Cut inch-thick sticks of several green woods and varnish the cut ends. Weigh pairs, and then split one of each through the middle and leave for several days and weigh again.

Why has the split stick dried faster? (Corky layer broken.)

Select similar pairs of hickory and of poplar twigs. Varnish the cut ends of each, and then split one end open and expose both to the same air. Which dries fastest? Why?

Take four equal sized pieces of cotton cloth and soak them well in water. Hang one in the sun, one in the shade, one in the cold, and put one in a tin box or under a tumbler. Why do some dry faster?

Why, especially, does the one in the tin box dry so slowly?

What ways do plants have to keep the natural moisture in?

Absorption and Radiation of Heat.

After much experimentation to find simple ways of illustrating these important points in the economy of plant life, I have found nothing better than the "pulse" or "palm" glass, to be used as a simple differential thermometer.

Get enough so that each pair of pupils can have one. Cut pieces of thick board about three inches longer and wider than the pulse glass, and make a slit in the middle in which the long connecting stem may set freely. This will support and protect the glass, and the inch and a half on each end and side will permit of the bulb being covered with various things.

Procure rings or squares of tin or cardboard large enough to surround the bulb at the distance of an inch,

and rising an equal distance above the glass. These may be bottomless collar boxes, vegetable cans, etc., but each *pair* should be similar. Next place strips of gummed paper up and down on the side or end of the bulbs, so that the position of the colored liquid can be marked when *equal* in each bulb, or when *highest* (the other bulb being empty).

Place the boards, each holding a pulse glass, on a level surface, and cause the liquid to become equal in each. Mark the place with a pencil on the strips of paper. Then in succession *empty* each bulb and mark the highest point, as before.

Making a cut with a knife at each pencil mark, scrape off all the rest of the paper strip, and then the equal and highest positions of the liquid will be easily told, even when one of the bulbs is concealed.

Experiment 5.—Let the pupil hold *one* (never *both* at once) bulb in the hand, in the sun, or near some heat, and learn that the **liquid** is always **highest in the coolest** bulb.

Get the problem before the class by the following questions:

What covering do roots and bulbs have? (Earth, snow, dead grass, etc.)

What covering do buds have? (Woolly, varnished, base of leaf, etc.)

What covering do stems have? (Corky bark.)

Of what use are these things to the plant? (Leave the question open.)

Experiment 6.—In the following experiments it is understood that one bulb is *covered* and, while the observing is done on the uncovered one, the interest is really in the effect of the *covering on the other*.

The liquid should be equal in each at the start, and the experiment is completed when, under the new conditions, it has become equal again. Use the rings when

earth, salt, etc., is used, and avoid draughts. Four experiments will be needed with each :

- a. Warm rooms to cold (in shade).
- b. Cold room to warm (in shade).
- c. Warm sunshine of rooms to cool sunshine outside.
- d. Cool sunshine to warm sunshine of room.

COVERING OF BULB.	HEAT LOST (RADIATION).		HEAT GAINED (ABSORPTION).	
	Seconds to empty covered bulb.	Minutes to become equal again.	Seconds to fill covered bulb.	Minutes to become equal again.
Moist earth.....				
Sod with dead grass.....				
Light leaf mold.....				
Coarse salt (= snow).....				
Gray woolen cap (= hickory bud)				
Loose, brown cotton (sumac)...				
Shining paper cap (poplar bud)				
Cork or bark cap.....				

Which coverings radiate heat best ? Which absorb best ?

What relation between the two ? *

What colors do we choose for hats and clothing in summer ? Why light ?

Will a *polished* stove heat better, or not ? Why not ?

Will polished shoes be best in summer, or winter ? Why in summer ?

Would the kettle boil quicker if its bottom were bright ? Why not ?

Why did the gilt sign Tyndall speaks of not burn ?

Which melts faster, clean or dirty snow ? Why ?

* See Tyndall's Heat, pp. 301-311.

Which colored clothes sink fastest when laid on snow? (Try and see.)

Explain in this connection the difference between **opaque** and **radiant heat**. Illustrate by a sheet of glass over one bulb of the pulse glass, the warming of green-houses and rooms into which the sun shines. See Tyn-dall's Heat, pp. 395-422, for the important action of the watery vapor in the air.

Why do clouds tend to prevent a frost?

Why will a thin cloth protect plants from a frost?

How does a tree protect the ground under and near it from frost?

Why does frost form on the boards of a walk and not on the nail heads? (Iron is a good conductor.)

Conduction of Heat.

Experiment 7.—Absorption and radiation of heat depend on the ability of the *surface* to receive or release heat vibrations.

Conduction is the mode of transmitting these vibrations in from, or out to, the surface, and depends on the material composing a body.

Apparatus.—To see how this compares in different substances, take heavy paper tubes (mailing tubes or old Roman-candle tubes) of about an inch in diameter.

Cut these an inch longer than your thermometers are up to the 40° F. mark, and in the end of each insert and glue inch-long plugs of the substances in the following table. Place a metal plate under the earth. Leave the "air" tube open at both ends.

Prepare a set of eight tubes for each *four* pupils, as they will need to work in pairs, and can only care for four tubes at a time.

Place this table on the blackboard for all to copy into their notebooks:

SECONDS.	TRANSMITTED HEAT IN. COOL CAN IN BOILING WATER.						TRANSMITTED HEAT OUT. HOT CAN IN ICE WATER.							
	Earth.	Cotton.	Cork.	Wood, cross grain.	Wood parallel to grain.	Air.	Salt.	Earth.	Cotton.	Cork.	Wood, cross grain.	Wood parallel to grain.	Air.	Salt.
15.....														
30.....														
45.....														
60.....														
75.....														
90.....														
105.....														
120.....														
Average .														
Rank....														

Which conducted *best*? Which *poorest*?*

Do solid, or porous, substances conduct heat best?

Why do we wear woolen in winter?

Why do fur and feathers keep animals warm?

How do double windows keep the house warm?

Which are better, solid, or hollow, walls to houses?

Why?

Why do some animals burrow in the snow in cold weather?

How does a blanket or sawdust keep ice from melting?

Explain the varying sensations of the bare foot on carpet, bare floor, zinc, etc.

* Tyndall's Heat, pp. 245-252.

8. A foundation having now been laid, through the study of plants (3 to 6) and the experiments of 7, the relation and **adaptation of vegetable life to its environment** can be considered, using the experiments to illustrate and explain.

Let us now see the meaning of what happens when winter comes.

Fall of the leaves. What was the work of the leaf?

Could this go on in winter? How does their fall help? (Prevents evaporation—while the root is resting—and loss of heat.)

State of the buds. Buried, as on the sumac. How help?

Woolly scales, as on the——? How help?

Varnished and gummy scales of the——? How help?

Air spaces inside the buds, as in——? How help?

Bulbs and naked buds? (Underground.)

Bark corky and scaly, as on——? What does this guard against? (Loss of sap and frequent and sudden gain or loss of heat.)*

Why does the snow melt slowly on the north side of a picket fence?

Under tufts of grass? In the thick forest?

Why are low heads best for apple trees in a changeable climate? (The daily freezing and thawing of the south side of an *exposed* trunk cause the bark to separate from the wood and die.)

Roots and underground stems. How are these protected? (By earth and fallen leaves.)

The ground does not commonly freeze to the ends of the roots. How will that help? (Conduction.)

Cloudy sky. What aid?

Slant rays of the winter sun. How help the plants to endure?

* See Tyndall's Heat, pp. 245, 246.

Moist air of winter. What aid ?

Snow. How help ?

9. **Stores of Food.**—What roots did we study ? Stems ?
Bulbs ?

Let us test for these foods, and see what they are.

Place the following table (except the filled-in data) on the blackboard for the class to copy :

Tests to recognize Plant Stores of Food.

SUB-STANCE.	Taste.	Soluble in cold water.	Iodine test.	Nitric-acid test.	Oil test. Rub on hot paper.	Fehling's solution.	Characteristics.
Starch..	Starchy.	No.	Blue.	.....	.....	.....	Not soluble in water, and blue with I.
Oil.....	Oily.	No.	.....	.....	Grease spot.	.....	Grease spot on paper.
Proteids .....	.....	No.	No.	Yellow.	.....	.....	Yellow with nitric acid.
Dextrin.	Sweetish	Yes.	Violet.	No.	.....	.....	Sweet, soluble, and violet color with I.
Sugar...	Sweet.	Yes.	.....	.....	.....	Orange color.	Tastes sweet, and orange with F. sol.

The starch may be "laundry," "corn," or common flour.

For oil, use bits of tallow. Rub on the paper of the notebook.

Proteids may be purchased ; made from flour by washing out the starch, or use "germ meal," or germs of soaked corn grains.

Dextrin can be bought.

Sugar ; pick grains from old raisins or candied honey.

Iodine solution ; dissolve 1 gramme potassic iodide in 10 c. c. rain water, add one quarter gramme iodine crystals, and dilute to 250 c. c. with water.

Nitric acid, strong ; colors proteids (gluten, albumen, etc.) *yellow*.

Fehling's sugar test ; buy.*

* For these tests, see Goodale's Structural, Bergan's, Bastin's, or other good Botany.

Use glass (test tubes or small vials) for dishes.

After the class has learned the characteristic tests, continue the table.

What Foods do Plants store, and where.

PART OF PLANT.	Taste.	Starch by iodine.	Proteid by nitric acid.	Oil by paper.	Sugar by Fehling solution.	What is found.
Root: Parsnip or dock.....						
Stem: Potato or Solomon's seal.....						
Stem: Crocus or gladiolus.						
Bulb: Onion or tulip.....						
Grain: Wheat, barley, or corn						
Seed: Pea or bean.....						
Seed: Peanut or sunflower.						
Sprouted seed: Malt.....						

Grate or scrape fine, squeeze through cheese cloth in water, and set away for starch to settle. Pour off the clear liquid, test part of it for sugar, and boil a portion, testing the scum for proteids and the clear portion for dextrin. Test the starch with iodine, and some of the original substance on hot paper for oil.

What kind of food seems most abundant? Which next? Are they soluble in cold water? What great gain to the plant from that? (Do not waste.)

They become soluble—sugar, etc.—in the same way the brewer or distiller turns starch into sugar.

Illustrate by telling how the diastase converts starch to sugar in beer and whisky making.

Why does this change not occur in winter? (Heat is needed.)

What is the change which takes place in the spring ?
(Starch to sugar.)

Illustrate by the sugar maple ; sugar beet ; rawness of green apples and sweetness of ripe ; sugar cane before the seed ripens ; parsnips in the spring ; tastelessness of long-kept watermelons.

Why was the food not stored as sugar in the first place rather than insoluble starch, oil, and gluten ? (Would waste by osmose, and spoil, as in making vinegar.)

10. **Results of these Preparations.**—(a) Endurance through the winter ; (b) early flowers and leaves ; (c) accumulated growth, giving rise to varied and contrasted size,* shape of head, form of spray, and useful timber, which annuals could not have.

11. Can you bring specimens of trees which seemingly do not need protection ? (Pine, fir, spruce, and cedar.)

How do these differ as to leaves and sap ? Why able to endure ?

Note the great addition evergreens are to the landscape, and as windbreaks.

12. **Teacher now reviews** (A) the adaptation of biennials and woody plants to endure, by a brief lecture.

B. *By Seeds.*

13. If time permits, examine more seeds than those examined in 9, and test for the food contents.

What are the most abundant food stores in seeds ?

What did the morning-glory (XXIII) teach us as to the conditions for germination ? (Heat, moisture, and oxygen.)

Why do seeds not sprout in fruit ? (No oxygen.)

Why not in winter ? (Too cold.)

* See Step XII.



Why do not the stores waste or spoil in an exposed seed? (Insoluble starch, etc.)

How is this insoluble food turned to soluble? (Diastase.)

If nuts or peach stones are kept in the cellar all winter and planted the next spring *they will not grow till the following spring*. Why not?

How are they gently cracked? (See 6, Step XX.)

14. What results from such seed? (Prolonged flowering season and rich stores of food for animals.)

15. Now hold a **searching oral review** by

1. Each tell what has particularly interested him.

2. Give specimens (some *new*) to tell about, as roots, leaves, seeds, or experiments. Class correct omissions or mistakes.

3. By questions from the teacher covering the entire ground.

Arrangements should now be made for a **supply** of material for the **Fruit** and **Corn** and **Bean lessons** next fall. Divide the work among the willing pupils and make a record of it, to remind all next spring.

Next step in plant work is XL—Fruits.

STEP XXXV.—WHAT THE TELESCOPE REVEALS.

Object.—1. To foster the interest in astronomy.

2. To study *light* in a simple way.

3. To increase the knowledge of our earth.

4. To prepare the way for the study of rocks (Steps XLIV and XLVIII).

The time needed will be about thirty lessons of thirty minutes each. Autumn is the best season of the year, as the constellations connected with the story of Perseus can be best seen, and the others appearing at that time reviewed.

Material needed.—Such lenses of different kinds, mirrors, spy or field glasses and telescopes, as may be available. Also a prism and the few chemicals spoken of.

As in all my suggestions, the *best* is advised, but much can be omitted, and a very simple and inexpensive set of apparatus made to do *good work*. The reading suggested below will indicate what things are needed and how to use them. I shall suppose the place to be the ordinary light schoolroom. Those who can have a dark room will be able to add much of interest to the class work.

Preparation and Literature.—Read the chapter on Light in any good work on physics of recent date; Miss Buckley's *Through Magic Glasses*; also pages 226–239 and 263–271 in Lockyer's *Astronomy*. Make yourself familiar with what the class has studied, the previous steps in astronomy, and the molecule lessons in this book. Then

read through this step, try all the experiments, and modify as may seem best.

OUTLINE OF THE STEP.

1. Connection by review questions.
2. Light a mode of motion, with a wave front.
3. Moves in straight lines. Ray.
4. Light itself is invisible, but makes other objects seen.
5. Its brightness varies inversely as the square of the distance.
6. Things are transparent or opaque.
7. Light falling on opaque objects is absorbed or reflected.
8. The angle at which light is reflected is equal to that at which it strikes.
9. Concave mirrors gather the light to a bright focus.
10. Light moves slower in dense than in rare media.
11. When rays pass obliquely from one medium into another the direction is changed.
12. Convex lenses gather the light to a focus.
13. Dim and distant objects can be seen better by the aid of certain mirrors or lenses.
14. Some of the things better seen by the aid of telescopes and field glasses.
15. Are nebulae distant clusters of stars? Laplace's hypothesis.
16. Only gases and vapors burn with a flame.
17. All things can be vaporized. Steel making.
18. Each element has a flame color of its own.
19. Each color is differently bent (refracted) by a prism, and when mixed can be separated into a spectrum.
20. The spectroscope a contrivance to do this separating well.

21. White light is composed of united waves of colored light.

22. The spectra of glowing solids and liquids are continuous bands, while the spectra of glowing gases and vapors have lines.

23. Laplace's nebular hypothesis.

24. Some proofs Laplace had.

25. What the spectroscope adds.

26. Constellations and the story of Perseus.

While well aware of the wide range of this outline, I am confident it can be successfully covered in thirty school lessons by the prompt and steadily progressive work which alone will enable the children to keep the connection. *Do not bring in other matters*; they will be provided for elsewhere.

1. **Connecting Questions.**—Do lifeless bodies have the power to start or stop themselves?

What is a force always acting, ready to cause motion if not prevented? (Gravitation.)

Through what distances does it act? (All.)

On what things? (*All*, from the sand grain to the huge sun.)

Is it equally strong at all distances? (No; it grows weaker as the distance increases.)

Can a body like a ball or planet have more than one motion at a time? (Yes.)

Which way will it move under this compound motion? (In a direction intermediate between the two directions.)

What will these conflicting forces tend to do? (*Strain* the body, and, if able, change its shape or break it in pieces.)

What benefit is this attraction of gravitation to us? (Holds us and all things on the earth's surface.)

Why do meteorites come to the earth? (Gravitation.)

Why do they burn up? (Friction of the air as they pass.)

What shows that the earth attracts the moon ? (Does not fly off.)

What shows that the moon attracts us ? (Tides.)

Why do the tides rise higher twice a month ? (Sun helps the moon.)

Why do we not fall to the sun ? (We are continually falling *toward* the sun, but have an *onward* motion, which as constantly carries us to one side.)

THE LESSONS.

2. Place a *lighted candle* before the class.

In how many ways does the light shine ? (All.)

Blow a *soap bubble*. In how many ways does it spread ?

We think that when anything gives light, waves of motion start from it and spread, as the soap bubble did, the shell-like waves spreading out more and more as they go out from the center.

(Blow another bubble, and talk of it till this spreading motion is clear).

An electric light hangs over a road. Tell me how many ways its waves of light spread. (Up, down, north, south, east, and west.)

Yes, and all the intermediate directions, like a bird's song in the air.

Why do I say "waves" ? (Because the shell-like waves continue to start from the candle or other shining thing one after another, just as though one soap bubble within another could start from this pipe.)

Now, different pupils tell me what light is. (**Light is a kind of motion.**)

3. Who has seen *lines* of light in a dark barn or room ?

What do you remember about them ? (Saw dancing specks.)

What were these specks ? (Dust.)

Where did the light come from ? (Some hole.)

What became of the rest of the sun or other light ?
(Was kept on the other side by the boards of the barn,
etc.)

Were these lines of light *straight*, or *crooked* ?
(Straight.)

Can you see around a corner ?

Through a curved or bent tube ?

How, then, does the little portion of shell-like motion
which enters your eye from anything you see travel ?
(Straight.)

If, then, we should take any tiny portion of the shell-
like wave from a light and follow the center off as far
as it went, in what direction would it move ?

Light moves in straight lines, and each line of direc-
tion is called a *ray*.

4. Let us next consider what it was you really saw in
the dark barn or room. Professor Tyndall tried two in-
teresting experiments. He put a hot flame under such a
beam of light, and a *pitchy black* place appeared over
the flame.

He next took a tight box with small glass windows in
three sides, and, having passed a strong beam of light
through the end windows, viewed it through the side one.
It looked as yours did in the barn. He now painted the
inside of the box with glycerin (which does not dry like
water), and, closing it tightly, set it aside for some time,
after which a beam of light passed through the ends
could not be seen at the side.

What change could have taken place in the box ?
(The dust had been caught by the glycerin.)

In the beam over the flame ? (The dust had been
burned up.)

What was it you really saw in the barn ? (Shining
dust.)

Why was the **light invisible** over the flame and in the box? (No dust.)

Can *light* which does not enter the eye be seen? (No.)

How would the sky look if no dust or watery vapor were in it? (Black.*)

5. Is a distant lamp as bright as a near one? (Yes, but it does not appear so.)

Why does it strain and tire your eyes to read at a distance from a lamp? (Dim light.)

Darken the windows the best you can while I light a candle and place it eight feet from the blackboard. Now, watch the shadow of this square book. I place it one foot from the candle. Mary may mark on the board the boundaries of the huge shadow. I place the book two feet from the candle and mark the smaller shadow. Now three feet from the candle and again mark.

What is this *shadow*? (The dark space behind something that stops the light.)

When was the most light cut off? (When the book was *near* the candle.)

When did the book stop the least light? (When farthest from the candle.)

Now open the blinds and let us measure the shadows, the last one *first*.

Taking this as our measure, how many times is it contained in the two-foot shadow? (Four times.)

In the three-foot shadow? (Nine times.)

So the portion of expanding light wave stopped by the book at *one* foot, at two feet had spread over—? (Four times the space.)

At three feet? (Over nine times the space.)

If the brightness at one foot be represented by 1,

* See Tyndall's *Molecular Physics*, pp. 341, 342, and *Fragments of Science*, p. 294.

at two feet it would be—? ($\frac{1}{4}$.) And at three feet? ($\frac{1}{9}$.)

Just as though I had 3 balls of butter to spread on some bread. I spread the first on one slice. The second on—? (Four slices.) The third on—? (Nine slices.)

Now, this is what is meant by saying **light varies inversely as the square of the distance.**

6. In turn, name substances on which light falls. Kate and Sarah may write them on the board as I tell them to. "Glass"—Kate writes. "Wood"—Sarah writes. "Chalk"—Sarah writes. "Water"—Kate writes, etc.

What word shall we write over glass and things which permit light waves to pass *through* them? (Transparent.)

And over Sarah's long list? (Opaque.)

What does that word mean? (Stops the light.)

Will all things fall more or less perfectly under these two heads? Yes, we can then say, "**Things are transparent**" or "**opaque.**"

7. If you look from a light room into a dark one, or down a long dark hall, what do you see? (Nothing.)

How would a deep hole, like a mine shaft, look? (Black.)

Boys sometimes cut faces in pumpkins and put a light inside. If one came toward you in the dark would you see the *pumpkin*, or the *face*? (The face.)

Which would you really see in the dusk of evening, the *blackboard*, or the *white writing*? The *printing* on that chart, or the *spaces* between the letters? (White spaces.)

Do you really see the *letters* in your reading book or a newspaper? (No.)

Now, light waves were going into the dark room and down the mine, and just as many fall on the blackboard and black letters of your book as on the white paper and letters.

What is the difference? (The dark holes had nothing in them for the light to fall on—like Tyndall's box after the dust had settled; and the blackboard and letters *kept*—or, as we say absorbed—the light.)

How about the things we really see? (The light waves that fall on them are turned to our eyes.)

Now this will help you to understand my words when I say, "**Light falling on opaque objects is absorbed or reflected.**"

8. How this sending off a reflection takes place we will now consider.

A ball thrown straight down bounces—? (Up.)

If thrown at an angle? (Glances away.)

A stone is dropped toward water? (Enters.)

When thrown at an angle? (Skips or glances.)

We stand in front of a mirror and see—? (Our own faces.)

We stand at one side and see—? (Things on the *other* side.)

Let us try some experiments about this. You may copy, while I draw near the top of the board, this straight line, 116 cm. long. From its center, with a radius of 58 cm., I will draw this semicircle below it.

What will be the length of the semicircumference? ($\frac{1}{2} \times 3.14 \times 116 = 182.12$ cm.)

How many degrees in half a circle? (180° .)

So each cm. of arc will nearly correspond to 1° . Draw a perpendicular from the center through the middle of the semicircle. Now begin on one side of this perpendicular and mark off 5 cm. of arc. Do this ten times on that side, and then begin at the center again and do the same on the other side. Next draw 20 lines from the center through these 20 points and as far beyond the circle as you can. Each one of the 20 little arcs made will measure an angle at the center of how many degrees? (5° .)

Beginning on each side, mark the first line "5°," the second "10°," and so on up to 50°. I will stick this large headed pin at the end of the perpendicular line and hold this bit of mirror just at the center. The light waves from the sun (or candle) fall on the pin and are reflected to the mirror. The mirror sends them along which line? Vary this by putting the pin (or any small object) on other lines and at other distances. See what line the reflected light follows, and read the angles. Here are small pieces of mirror I will lend you. After school each draw one of these semicircles on thick paper pinned to a board, or even on the board, sand, or any proper place, and find out how the **angle of incidence** (at which the light strikes a reflecting surface) compares with the **angle of reflection** (at which it is sent off).

(The next lesson.) I should like to hear from different ones as to what they did and observed. (Class tell results, etc). Then what shall we conclude about the rebounding (reflection) of light? (That "**the angle of incidence is equal to the angle of reflection.**")

Where are these angles measured from? (A perpendicular to the plane of reflection or to the surface that reflects.) (Teacher explain.)

9. Why do lamps have reflectors? (To turn much of the light toward some place or direction.)

What is the shape? (Concave.)

Here is a curved line to represent the concave reflector, and these parallel lines going to it we will call rays of light. Which way will they travel after reflection? (*Inward* a little.) In which case they will at last *meet* at a point called the **focus**.

Why does the light from a reflector seem so bright when the eye is in its range? (There are *many* rays turned so as to enter the eye at the same time—i. e., the reflector concentrates the rays on the point where the eye is.)

Going down the Mississippi River on a steamboat at night I was much interested in the way the pilot used his "search light" to find the objects on shore by which to steer. A large concave reflector on the bow of the boat threw the rays of a powerful light in one straight beam. An endless rope enabled him to turn this in any desired direction, making the objects on which the powerful beam fell clear as noonday. In this case the *light* was at the focus, and so the beam of light went out in parallel rays. Let us imagine the light removed and the *eye* placed at the focus? (The gathered rays would cause **dim objects to look brighter, and distant objects more distinct.**)

Sitting in a scientist's parlor one evening the lights were put out, and when our eyes had become used to the darkness we could barely distinguish the objects outside an open window. Our host then placed on the table, facing the window, a slightly hollowed plate of polished metal he had been making for a telescope. To our delight on looking at it, trees and other objects became beautifully distinct. What caused it? Would such a reflector be helpful in looking at the *moon* or *stars*? How?

10. **Substances** are said to be **rare** or **dense** according as their molecules are widely scattered or close together.

Name something transparent, denser than air. (Glass.)

Rarer than glass? (Water.)

Rarer than air? (Ether of space)

A stone is dropped into water, or a bullet fired straight into wood. As these leave the rare air and pass through the denser water or wood, how will they move? (*Straight on, but slower.*)

Why slower? (Denser substance is harder to pass through.)

Suppose I stood on a high bridge and dropped the

stone on some thin ice? (Would be checked by the *ice*, but go *faster* again in the water below.)

Air, water, glass, and other substances which permit light to pass through, we call *media*. Experiments—which we can not make—have proved that **light waves move slower in a dense than in a rare medium.**

11. In what is to follow, each must keep clearly in mind the *double* motion of a light wave. Not only is it moving *on* in a straight line, but the spherical wave front is also *spreading out* in all directions at *right angles* to this onward motion.

Does air hinder your walking or running? (A little.)

How about water? (More.)

Did you ever run down the beach into the water? What was the effect of your feet entering the water first? (Nearly tripped forward.)

Why? (Feet were held back by the water, while the body tried to keep on.)

Which way is a man apt to fall on jumping from a moving wagon or train? (Forward, the way the train moves.) Why?

Which way do men on the top of rapidly moving freight cars lean? (Forward.)

Why? (Wind makes them unable to stand up straight without danger of falling backward.)

Why does a wave “break” on the beach? (Lower part is retarded by the bottom, while the upper portion, continuing its motion, pitches over forward in a crest of foam.)

Should the wave strike a pier or pile, what—? (Will reunite beyond it, and go on.)

Will this reunion be *quietly* made? (No; with more or less *confusion*.)

What is there in the vast space through which the earth and moon travel? (Nothing as dense as *air*, but there does seem to be a *something* able to carry the heat

and light waves, and still so *very, very* rare as not to retard to any measurable extent the huge bodies which rush through it.)

We call this very thin medium **ether**.

Now, light waves pass through this *ether*—as we found from Jupiter's moons—how fast? (186,000 miles a second.) (See page 10.)

Will it pass as fast through air? (No.)

Through water? (Slower.)

Glass? (Slower still.)

If the waves of light pass straight from a rare substance (air) into a dense medium like water or glass, what will happen? (Go straight on with a changed velocity.)

Think carefully before you answer the next question.

Suppose the ray enters *at an angle*, so that the bottom (for example) of the spherical wave front strikes the water or glass before the top? (The wave will *trip*, like the boy in rapid motion whose feet suddenly are retarded by water, or like the crest of a "breaker.")

How about the direction of motion? (Will be *changed*.)

There is **an illustration** which has been very useful to me. You have seen a pasture where the grass was smoothly eaten down: is it easy to walk on such a place? We will suppose a company of soldiers had camped in this pasture, and for their camp fires had carried away the fence from a field of tall grain * which pushed a corner out into the pasture. Suddenly the men were formed in line and ordered to march as rapidly as possible in a direction which took them across the corner of the field. As the column came to the tall grain one end of the line got into the thick grain first, and while struggling through it the end on good walking got along faster, and when at last all were in the grain the direction of

* *Deep mud* will do as well.

march had swung a little toward—what? (The *widest* part of the corner of grain.)

After a while the men began to get out, but those last *in* were first *out*, and so kept gaining, and the front changed a second time.

We will all draw this.

F will represent the field, *A* the column when it started, *B* the column when all were in, and *C* when all were out.

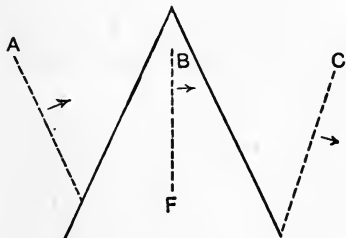


FIG. 6.

Toward which part of the field did the direction change each time? (Widest part.)

I trust you now understand that **when a ray of light passes obliquely from one medium to another its direction is changed.**

12. Suppose a shallow pond were lens-shaped—thickest in the middle—and a line of men marched through as rapidly as they could. (The end men would close in upon the center ones, and, if each kept, on would *meet* in a *group*.)

What that we have talked of does this gathering together remind you of? (The focusing of the rays by a concave mirror.)

Here are some lenses for you. Where are they all *thickest*? (In the middle.)

Now, remembering what we have talked of, take them and experiment till the next lesson.

What have you learned with your lenses? (Near things look larger. The light is brighter at the focus. Distant things look small and *inverted*. The lenses gather the heat, and answer for burning glasses.)

Good! These are all important observations, and all

the better because I did not help. Are the lenses larger than the pupils of our eyes? Can you think of any service such lenses can be to us in our star studies? (Make stars and moon brighter and clearer.)

In what *position* will they appear? (Upside down.)

And in *size*? (Smaller.)

Convex lenses gather the light, and two or more of them may make distant objects look larger and more distinct.

Keep your lenses and try some of these things again.

13. **Telescopes and Field Glasses.**—Name a way to make dim or distant objects more distinct? (By two or more lenses of different focal lengths properly combined.)

There are many ways of fixing these mirrors and lenses, which you will find described in books on physics or astronomy. By the aid of the cuts in these some of you may be able to construct simple instruments to observe near or distant things.

14. Now **have the class gather on clear evenings** with all the helps they can bring, and observe as many as possible of the following objects. Compare on the spot with the cuts and descriptions in books suggested in the opening pages of this step.

1. The moon. (See Magic Glasses, pp. 10-23.)

2. The phases of Venus.

3. The disk and moons of Jupiter.

4. Saturn and rings. (Lockyer, p. 148.)

5. Some double star. (Mizar in the "dipper.")

6. A star cluster. (Lockyer, p. 47, or Magic Glasses, p. 163.)

7. A nebula—that in Andromeda. (Magic Glasses, p. 163.)

15. The **star clusters** and **nebulæ** looked so much alike at first that they were all supposed to be clusters of stars, so very distant as not to be separately seen. The

famous astronomer in whose honor the sign of Uranus was made ♃ (an H with a planet suspended from the crossbar) studied these clusters and nebulae with much care, and discovered many new ones. As Herschel observed and catalogued these, the idea, before suggested by others, that some were *not* clusters, grew in his mind. What, then, were they? Simply *glowing gases*, and our own *solar system* was once a nebula. Later, this thought was taken up and written about by a brilliant Frenchman named Laplace, whose conception of how a hot central sun like ours, surrounded by planets and their moons, came into being, is known as **the nebular hypothesis of Laplace**. His conception (or idea) is more and more accepted by men of science, and I want you to know something of this *wonderful* and *helpful* story. Let us get a few needed conceptions first.

16. Only gases and vapors burn with a flame.

Name some things which burn with a flame. (Wood, oil, coal, gas, tallow, etc.)

Is it wood (and coal) which darts and flashes up the chimney or rushes in hissing jets from the cracks? Can *solids* behave so? (No, only the *gases* into which the heat turns them.)

So with the candle, and all other things.

Before we have *flame*—? (We must have a gas.*)

17. Cast iron is very impure and brittle. It has been found that the cheapest way to make the hard, tough *steel* used for rails, etc., is to melt the iron, burn out *all* the sulphur, carbon, sand, lime, and other things mixed with it, and then add to the purified iron just enough of

* The teacher should now take the class to some Bessemer steel works to observe. If this is *impossible*, gather cuts and illustrations from chemistries or other sources and make the idea as vivid as possible by words.

the carbon, which *must* be present with it to make good steel.

This is the way it is done: A huge one-sided pot, called a "converter," is made of iron and lined with fire brick—as our stoves and grates are—to keep it from melting. The bottom of this converter is full of *holes* about the size of one's finger. These holes all end in a chamber connected with powerful air pumps called "compressors," which can send a blast of hot air at such a furious rate through the holes that even good-sized *stones* would be sent flying out at the mouth if they chanced to be in the way of the blast.

This converter is hung like one of those urns used to make tea on the table, so that it will tip up or down.

When all is ready this giant pot is tipped till the mouth opens at the side, and into the huge bulge below is poured about half a car load of melted iron.

The blowholes in the bottom are opposite the mouth, and so this pond of molten metal does not rise to them.

A signal is given, the huge compressors start, and as the whirlwind of hot air sweeps through the tubes in the bottom and over the surface a shower of bright sparks fills the air. The converter now begins to slowly turn, and as the mouth rises to a hole in the iron roof above, the melted metal flows over the holes in the bottom and the blast of air bubbles up through and rushes with a deafening roar of flame from the mouth. This is kept up ten or fifteen minutes, and while we are waiting to see the end let us think (no one could *hear*) what is in that flame.

As the blast of hot air rushes through the melted mixture the iron, sand, lime, and other things become *vapors*, which burn on coming to the air, like any other gas, and that flame, so bright that we can hardly look at it, is made by the glowing vapors of these things. As the time passes the small quantities of injurious sand, sul-

phur, lime, and carbon disappear in flame along with some of the iron.

When the color of the flame shows that little besides iron is burning, the converter slowly turns back till the metal is off the blowholes; then the blast stops, some other melted iron with just enough carbon in it to make the whole into steel is poured in, the mouth then descends till the whole batch of melted steel pours out into a huge "ladle" placed below, and there *we* must leave it.

Now, when we want to *melt* steel we use dishes made of *graphite* (like the "lead" of pencils). When we want a very intense light we heat a piece of *lime* till it glows (but does not burn); and *sand* is the principal thing in the unmeltable fire brick which lines the converter.

Yet we have seen that even these three things, so difficult to melt, were *vaporized* by intense heat, and became a sheet of *glowiny flame*.

What shall we think of *other* things about us? (That **everything can be turned into glowing gas or vapor.**)

18. In telling of Bessemer steel making, I used the words "when the color of the flame shows that little besides iron is burning." What "color" has to do with it I can now lead you to see. Here is an alcohol lamp. Having been well washed and a new piece of wick and fresh alcohol put in, the flame is nearly colorless.* In these little dishes I have five things I want you to see the flame color of, so in each I will dip a match stick or splinter of dry wood to hold in the alcohol flame. We will now darken the room as much as possible, that you can the better observe while I hold one after another in the flame.

No. 1 solution is of crystals of some *pure* potash salt— KClO_3 or KNO_3 .

No. 2 solution is of strontium nitrate— $\text{Sr}(\text{NO}_3)_2$.

* A clean Bunsen burner will be even better.

No. 3 solution is of common "bluestone," or copper sulphate— CuSO_4 .

No. 4 solution is of copper chloride— CuCl_2 .

No. 5 solution is of common table salt or soda.

(Introduce these into the flame in the order given or they may interfere with each other.)

No. 1. What color to flame? (Violet, of the metal *potassium*.)

No. 2. What color to flame? (Crimson, of strontium.)

No. 3. What color to flame? (Green, of copper.)

No. 4. What color to flame? (Blue, of chlorine and copper.)

No. 5. What color to flame? (Yellow, of sodium.)

So I might go on, and by greater heat and proper apparatus get the flame of every element we know of, and find that **each element has a flame color of its own.**

19. Let us think again of the whirling rod we talked of in the molecule lessons (Step XXXI, Lesson 16).

After the *separate blows* became too fast to distinguish, we had——? (Sound.)

What did Count Rumford teach us? (Heat is a mode of molecular motion.)

The blacksmith? (More frequent vibrations gave red light.)

Now, if his shop was dark and a hole in the wall opened into another room (also dark), what might we see on the opposite wall? (A spot of red light.)

In what direction? (Straight through from the red-hot iron.)

If this glass **prism** (whose cross section is like the grain field the soldiers marched through) were placed by the hole so that the light had to pass through——? (The spot would **change to one side.** ¶ 11.)

Would it still be *red*? (Yes.)

If the vibrations increased the red would become——? (Orange.)

Yes; still the orange spot would not be where the red was, but a *little farther away* from the straight line.

Next would come——? (Yellow.)

This would be still more bent.

What other color would follow? (White.)

Each of which would in succession creep farther and farther away from the spot made before the prism was put in the way.

Which light has the slowest vibrations? (Red.)

Which the most rapid? (Violet.)

Are these vibrations equally changed by a prism?
(No.)

Which are bent most? (The *most rapidly* recurring.)

The least? (Slowest.)

If these colors were all united in one beam how could we separate (disperse) them again? (Pass the light through a prism.)

What color would be bent least? (Red.)

Give the order of the remaining colors. (Orange, yellow, green, blue, violet.)

What colors did I show you in the flame? (Red, yellow, green, blue, and violet.)

How would these colors be bent (refracted) by the prism? (Each one *differently*.)

Suppose I put all in the flame at once? (The more intense colors would cover up or hide the weaker.)

But would all the colors be in the flame? (Yes, *must* be there, only can not be distinguished.)

Can you think of any way to separate them so that each can be seen? (By a prism.)

Is it not wonderful! If all the colors mixed in one ray pass through a prism, **each color is differently bent, and will be separated in the colored spectrum.**

20. A *single* lens or prism is only able to spread out the light a little, so several prisms are arranged,

one after another, in an instrument called the **spectroscope**.*

With this the colors are widely separated into a long band, where they can be examined.

If we turned a spectroscope on our mixed flame what would it show? (Each color by itself.)

And we could thus tell——? (**What substances were burning.**)

21. Having learned that each color is differently bent in passing obliquely from one medium into another, and can thus be separated by the prisms of a spectroscope, let us notice something wonderful about common **white light**, as we call that which is not colored.

Who has ever seen a colored band of light? Where? (On tablecloth or wall.)

Was the sunshine in the room? (Yes, and it must have passed through the prislime corner of something made of glass, which not only *turned* the ray but *spread it out* like a colored fan.)

What kind of light was it that entered the glass? (White.)

And it came out——? (A colored band.)

When do we see a **rainbow**? (When we look at the reflection of the sun shining on falling rain.)

Of what shape are falling drops? (Spherical.)

Where is a sphere thickest? (In the middle, like a lens.)

What light is it that enters these little raindrop lenses? (Sunlight.)

And what happens to this white sunlight? (Its rays are bent and *separated* by the drops till we see the beautiful band of colors called a rainbow.)

Other examples are seen in broken glass or ice, films of oil on water, soap bubbles, etc.

* Lockyer's Astronomy, chap. xv.

What, then, must we conclude about white light?

White light is composed of all the colors united and condensed.

22. How were the colors arranged in the rainbow, or the colored light on the table or wall? (A **continuous band**.)

If you could see the spectrum of gases you would notice a difference.

(Show in some book,* or have drawn on the board.)

What is it? (**Burning gases have bright lines** of color.)

Yes. That of sodium is in how many? (One yellow line.)

How would you know burning hydrogen gas? (One orange and two blue lines.)

And oxygen? (Many lines.)

Students have found that these lines are *always the same* in position and color.

Remembering now that glowing **solids** (sun, hot iron, etc.) give **continuous** spectra, while glowing **gases** give spectra with **bright lines**, let us turn the spectroscope on the steel-converter flame.

What shall we see? (The bright lines of burning iron, lime, sand, oxygen, and other gases and vapors.)

If we looked at the melted steel as it was poured out? (The continuous spectrum of a hot liquid.)

At a bar of hot steel in the rolling mill? (Continuous spectrum of a solid.)

We thus see *two* classes of spectra, and say **spectra may be "continuous" or "bright-lined."**

23. We have learned that flames can only come from burning gas or vapor. That each substance has its own bright lines of color in these flames which are differently bent (refracted) by the prisms of the spectroscope, thus

* Magic Glasses or Lockyer.

enabling us to tell whether a light we may see comes from a glowing white-hot solid or from burning gases or vapors, and also what is burning in them.

That all substances we know of can be vaporized and give the bright-line spectra. That when heated sufficiently in the liquid or solid form, all these substances give white light, whose spectrum or band of color is uncrossed by dark lines.

Now, as **Laplace studied** the planets and moons of our system and in connection thought on the then recent discoveries of Herschel, the idea grew in his mind that the sun and all his attendant planets may once have been a *nebula*—a **great cloud of glowing gas**.

In what state would all the sand, iron, carbon, lime lead, gold, etc., be? (In a brightly glowing gas.)

How large was this cloud of intensely heated gas and vapor? (It must have extended far beyond the most remote planet—Neptune.)

Is space, the region off into which we look to see the sun or stars, hot, or cold? (Cold.)

Then this nebulous cloud would gradually——? (Cool.)

As it cooled, it would, as other things do——? (Grow smaller.)

In some unexplained way Laplace thought this contracting gas began to *revolve*.

This would make the outer portions try to do what? (Fly off.)

Yes; but gas could hardly take the form of a *drop*, so it was supposed a *ring* separated and went on revolving. As the remaining portion contracted more and more a second ring was given off and left behind, then a third, and so on till at least *eight* principal portions had separated.

Now let us go back to the first ring. Left behind, this would cool more rapidly, till at last it is supposed

the ring *broke* and gathered into a *ball*, and as the ring broke this ball acquired a revolving motion on its own axis.

This revolution in time caused a portion to separate from the ball, and this, the theory claims, originated what? (Neptune and his one moon.)

What came from the second ring? (Uranus and six moons.)

From the third ring? (Saturn, his eight moons, and several *rings*.)

From the fourth ring came——? (Huge Jupiter and his five moons.)

From the fifth? (Mars, with two moons.)

From the sixth ring? (Our *earth*.)

And as this huge globe of heated matter cooled and contracted, what at last separated? (Our moon.)

From the seventh portion originated——? (Venus.)

And the eighth? (Mercury.)

What name do we give the portion now left? (Sun.)

These are some of the points in Laplace's brilliant conception of how our solar system came to be.

24. **Some Proofs.**—Here are some shot for each of you.

How do you imagine so *many* very round pieces of lead are made? (The lead is taken to the top of a very high tower, melted, and allowed to drop through a kind of sieve into a tank of water at the bottom of the tower.)

Let us think of this very carefully.

As the lead leaves the sieve it is in what state? (Melted.)

What does it rest on? (Nothing.)

Are the molecules in a liquid free to arrange themselves? (Yes.)

How will they do this in an *unsupported drop of liquid*? (Will attract *each other* and gather about the center, forming a *sphere*.)

If such a sphere of liquid were made to *spin* on its

axis—? (Would bulge at the equator and flatten at the poles.)

Do we know of any such rotating spheres? (Sun, earth, some, and probably all, the planets.)

Are they bulged and flattened? (Our earth and some of the other “members of the family” certainly are.)

But the earth is not “liquid”? (No; but its rocks and heated interior plainly teach it *once* was.)

If Laplace were correct, what should we expect the remaining portion of the nebula to be like? (A huge, hot, revolving sphere.)

Just what our sun is.

What, then, are some of the proofs Laplace had? (A hot, central sun, surrounded by planets and their moons, all bearing in shape and motions unmistakable marks of their common and fiery origin.)

25. Now let us use what we have learned by fixing our spectroscope on the end of our telescope.

Here is a colored chart of the spectrum of the *sun*.*

Is it a continuous, or bright-line, spectrum? (Continuous, with *dark* lines.)

I can only tell you now that by these dark lines we have learned to tell what is burning in the great sun, 93,000,000 of miles away.

What would be the spectrum of the *moon*? (Same as sun.)

Stars also have a spectrum. Here is a chart of one (Aldebaran) much like the sun.

If we could gather, with a large lens or reflector, as much light as possible from the *star cluster* in Andromeda, and observe the spectrum? (Still continuous, like the sun, and bright stars.)

How will a real nebula look? (Bright-line spectrum.)

* Magic Glasses, p. 127.

Are the real nebulæ solid, liquid, or gaseous? (Burning gases.)

Laplace only guessed this to be so. Now it is *proved* by the spectroscope, and adds much strength to his theory of the solar and other systems.

Here we must leave this interesting subject. I trust it has given you new and correct ideas of *light*, and of the useful instruments which aid us in our star studies. It has also added one more chapter in the wonderful history of this earth, which you will find more and more interesting as you study about her.

26. **Constellations.**—For this step find those connected with the story of Perseus,* which can be well found at this season (see Lockyer, p. 191, "October 16, 8.30 P. M.," or "November 7, 9 P. M.," or Serviss, chapter iii). This brave son of Jupiter having received the shield of wisdom (Minerva) and the sword and winged sandals of Mercury, secured the "hat of darkness" from Pluto, and, thus armed and invisible, slew the terrible Medusa. From her blood sprang the winged horse **Pegasus**. Returning home with the Medusa's head, he spies beautiful **Andromeda** chained by the sea, turns **Cetus**, the sea monster coming to devour her, into a rock by showing the **Medusa's head**, and gains the permission of **Cepheus** and **Cassiopeia** (father and mother of the maid) to marry their daughter.

Read this with or to the class, and in connection make star charts, as before, of the constellations.

In finding the groups, proceed as follows:

1. Review the Great Bear (dipper).
2. Follow the straight line from the "pointers" to the north star and on beyond till a square of four bright stars is found. These mark the winged horse **Pegasus**.
3. The northeast one of this "square of Pegasus" is

* Bulfinch, pp. 139-154, Greek Heroes, and Burritt.

also in the cheek of fair **Andromeda**. Now start from the diagonally opposite corner star of the square and follow the line through the star in the cheek to two others in her girdle and foot. These three will mark the group.

4. Follow the line through the star in the foot till it crosses the Milky Way, in which, nearly at an angle of 45° to that direction, lie three bright stars, marking the constellation of **Perseus**.

5. To one side (south) of the *space* between the middle and last stars of Perseus is a group of five stars (four rather faint) forming the **Medusa's Head**, which Perseus carries in his hand.

6. In the same direction will be seen the bright pair of stars in the Ram's Head, and beyond these lies **Cetus**, the sea monster. A line from the north star between the two upper stars in Perseus and through the bright star in the Medusa's Head will pass near the brightest star in Cetus. Then find the irregular circle of seven stars about the one in the eye.

7. Returning to Perseus, next him find **Cassiopeia** (the chair or "W"), which we have before used to find the star cluster and nebula (Buckley's Magic Glasses, chapter vii).

8. Beyond Cassiopeia, and between her and the Swan, is **Cepheus**. Three stars of medium brightness, lying along the Milky Way on the side nearest the north star, mark this group.

Suggestions as to star lanterns, places of meeting, etc., will be found in Step XXX.

The Review of this step will, as usual, be placed at the beginning of the next, but can also be used here with profit, although such work as I have outlined does not need the uninteresting retracing of steps implied in the term *review*. Being largely a matter of the child's personal observation and experience, it will never be *forgotten*, and the only fitting supplement to such work is

to use the present acquirements as keys to new and greater knowledge. Only be sure the impressions are *correct*, and then *press on* wherever the way opens.

The next step in this subject is XLII—The Earth's Early History.

STEP XXXVI.—CRYSTALS AND CRYSTALLIZATION.

Object of these lessons :

1. To review surface and solid forms. (Steps XXI and XXVI.)
2. To prepare for minerals. (Step XXXVII.)
3. To prepare for soil and rock making. (Steps XLIV and XLVIII.)

Time needed.—About twenty lessons of thirty minutes each.

Material for class of thirty :

30 clay boards and molding clay, of Step XXVI.

30 magnets, of Step III.

Box of toothpicks or wires.

2 pounds each of alum, copper sulphate, and iron filings.

Fragments of glass, crystalline calcite, rock salt, and galena.

60 glass sauce dishes. (Do *not* use porcelain.)

Set of crystal models.

Expense.—Almost *nothing*. Many of the things are already in stock, and the rest can be gathered, brought by the pupils, or cheaply bought. Good crystal models are, however, *expensive*, but can be dispensed with, except those made in the solid form, Step XXVI, or by the following directions :

Have some skilled carpenter get out four rods of apple, cherry, black walnut, or other fine-grained and well-seasoned wood, and cut them into blocks according to

the directions in the table on pages 224 and 225 (dimensions are in *inches* and fractions of an inch).

Cut thirty of each. The pupils can sandpaper the ragged edges. The cost should not be over two dollars, and a valuable lot of material will be secured. A bright carpenter might make some pyramids, etc. (see Step XXVI), if models were supplied.

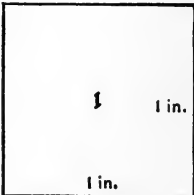
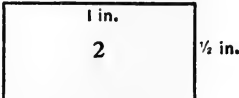
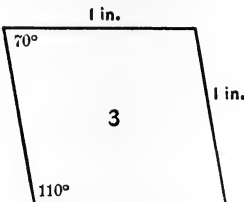
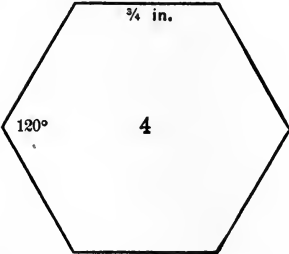
Preparation of Teacher.—Ruskin's *Ethics of the Dust*, Dana's *Manual of Mineralogy*, Tenney's old but helpful *Geology*, and Crosby's *Common Minerals and Rocks* have been my best aids in the way of books, but doubtless other and more recent works are to be found. The remainder of my study has been with the crystals and experiments.

I would advise the teacher who is to give these lessons to rely mainly on the latter, and only use books as need may arise. Gather your material and all the crystals you can find. Then go through the following lessons and verify each point, modifying such as your material and surroundings may require. Then give the lessons, and "practice will make perfect." A review of Step XXXI, on molecules, may aid.

THE LESSONS.

1. Show (and converse about) all the crystals you and your pupils can bring together. An interest will thus arise.

2. Give Linnaeus's statement: "**Minerals grow, plants grow and breathe, animals grow, breathe, and move.**" Such fixed limitations do not actually exist, but this will introduce the subject, and the exceptions will appear in the proper place and time. Bring the class to some sense of the fact that most kinds of mineral matter, although seemingly *dead*, always have a particular way in which the molecules come together when free to move. This particular form may undergo numberless modifications

CROSS SECTION AND DIMENSIONS OF ROD.	Length of rod needed.	Length of blocks to cut.
 <p>1 in. 1 in. 1 in.</p>	120 inches of No. 1.	1 inch. 2 inches. $\frac{1}{2}$ inch.
 <p>1 in. 1/2 in. 2</p>	130 inches of No. 2.	2 inches. 2 inches.
 <p>1 in. 1 in. 70° 110° 3</p>	95 inches of No. 3.	$\frac{1}{2}$ inch. 1 inch. $1\frac{1}{2}$ inch.
 <p>3/4 in. 120° 4</p>	100 inches of No. 4.	1 inch. 2 inches.

Angle of cross cut.	Shape of form made.	System of crystallograph.
Square across	Cube	Monometric.
“ “	Right prism (long)....	Dimetric.
“ “	“ “ (short)....	Dimetric.
“ “	Rectangular prism ...	Trimetric.
Square across, but on 20° slant.	Oblique prism.....	Monoclinic.
• Square across	Rhombic prism.....	Trimetric.
20° slant, both across and down.	Rhombohedron.....	Hexagonal.
20° slant, both across and down.	Doubly oblique prism.	Triclinic.
Square across	Short hexagonal prism.	Hexagonal.
Square across	Long hexagonal prism.	Hexagonal.

by the cutting off of corners and beveling of edges, but through all it remains true to its own system, and certain angles will remain constant even to *seconds* of a degree. Read parts of Ruskin to the class (Pyramid Builders). Through all the exquisite forms of the snowflake, the feathery hoarfrost, the solid ice, or the delicate tracery on the window pane, runs an exactness and symmetry which is awe-inspiring. They crowd and jostle each other out of all semblance to the typical hexagonal form, but let even a *corner* have the freedom to grow, and it is rigidly true to its system. When, as frequently in a dry snow, the molecules of watery vapor floating in the air succeed in escaping interference, a beautiful six-pointed star results, with the three lines joining the six points of equal length, and forming an exact angle of sixty degrees with each other.

3. **Some hint of how this happens** can be given in the following experiment :

Give each pupil half a teaspoonful of fine iron filings and a bar magnet.

(a) Remove the magnet well away and drop the filings over sheets of paper. We can suppose these like the molecules of an uncrystalline substance.

(b) Remove the filings and lay the paper over the magnet. Now sprinkle the filings over the paper again and see what beautiful curves are formed. Each particle of iron now swings into its proper position, and *order* takes the place of *chaos*.

In some such way must the molecules and atoms be guided to their places.

That they may arrange themselves, it is evident they must be *free to move*. Let the class tell what conditions of matter will permit this. (Vapor, as seen in the case of snow and sulphur; liquid, as in melted iron and water; or in solutions, as salt, alum, and copper sulphate.)

4. **What kinds of molecules will thus unite?**

Let us try some experiments before we answer this.

Here are two bottles (fruit jars) with hot solutions of alum and copper sulphate. I put pure rain water on the substance several days ago, and have frequently stirred the water. As some of the substance is still undissolved, I know the solution is saturated (has all it can hold).

Every crack and crevice between the water molecules is full of molecules of alum or copper sulphate.

Are these molecules free to move? (Yes.)

Why did I *heat* the water? (So that it could hold more of the mineral in solution.)

Even these enlarged spaces, then, are full.

What will happen when the water cools? (Its molecules will draw closer together and some of the mineral be forced out.)

And I shall find a lot of molecule dust on the bottom? (No; cohesion will make solid masses of them.)

Being free to move, these molecules will arrange themselves in certain ways, and these "masses" will be——? (Crystals.)

After the cooling has excluded all the mineral it can, how shall I compel the water to deposit still more? (Dry it away.)

Let us test these conclusions. Here are sixty warm glass dishes and sixty pieces of cardboard large enough to cover them. Each take two pieces of cardboard and write your name plainly on them. Now each take two dishes, and after wiping free from dust place one on this table near the register (or any safe place where they will cool *slowly*). I will then fill it 1 cm. deep with alum solution. Cover it with one card, and on the card place the other clean and warm dish for me to fill as before with the copper-sulphate solution. Place the second card on this dish. Now we will cover all with a cloth to keep out the dust.

I have warmed the dishes and put all in this warm place, where the temperature will slowly fall, till morning, when we will see if *cooling* does make hot solutions deposit mineral matter.

In the morning examine the dishes and see the crystals which will have formed. To test the effect of evaporation, place the dishes where there will be a free circulation of warm air (*carefully* exclude *dust*), and leave till the water is nearly dried away. Let the pupils now keep two or three of the best crystals, and return the rest of the liquid and imperfect crystals to the proper jars of solution.

5. Do hot solutions of mineral deposit crystals in cooling?

Does evaporation cause the same deposit?

What will control the *size* of the crystals? (*Slow* cooling or evaporation will cause *large* crystals.)

Then a crystal needs *time* to grow as well as anything else.

If, then, I find large crystals—? (They were long in growing.)

If small ones? (They formed quickly.)

If perfect in *shape*? (Were free from the crowding of others.)

Yes, and you can much improve such crystals as those made by keeping two or three free from the others and *turning* them over frequently.

Why do I say "turn over"? (Molecules can not freely get at the underside as it rests on the dish.)

Each may now clean one dish for a most remarkable and instructive experiment. See, I am going to **mix** the **white-alum** solution with the **blue-copper sulphate**. I will pour a double quantity in each dish in order that we may see the influence *time* has, and, being careful to keep out dust, leave till evaporated three fourths.

6. While waiting for this evaporation review the class

on the plane figures and solid form of Steps XXI and XXVI. This will be time well spent if a thorough familiarity is gained of the various angles, triangles, quadrilaterals, etc., and the solids which they may inclose.

7. When three fourths of the water is evaporated from the mixed solution remove the cake of crystals in each dish, dip it *quickly* into some ice-cold water to rinse off the surface, and then place on papers to dry.

What remarkable thing has happened? (A **perfect separation of the crystals**, alum and bluestone standing side by side, or even *on* each other, and still *pure*.)

So certain are *crystals* to be pure, that when great purity is needed, as in some chemicals, it is secured by crystallizing the substance, washing, and recrystallizing again, if need be.

Were the molecules of the two substances *thoroughly* mixed? (Yes.)

How did they come to separate? (Similar molecules attracted each other.)

Is it not wonderful that they never make a mistake either as to what molecules to join nor the form the crystal is to take?

Would the same thing probably happen to mixed *vapors*? (Yes.)

How about melting things together like iron and lead? (Also separate.)

If I could *melt* several different kinds of *minerals* together or have them in the same solution, do you suppose they would also separate? We shall see, some day, how important this is.

To-morrow we will further illustrate this, if it is *very cold*.

Who will bring about a litre of strong salt and water and a bowl? (Mary.)

Who will bring about a litre of coffee water and a bowl to hold it? (Kate.)

Who about a litre of vinegar and a bowl? (John.)

Who the same volume of inky water and a bowl?
(Samuel.)

Who will bring a bowl to hold the rest of this alum solution? (Thomas.)

Who a bowl for this copper sulphate? (Paul.)

Samuel, will this inky water freeze *pure*? We will see.

8. If very cold on the morrow, put the things called for yesterday 6 to 10 cm. deep in wide-mouthed bowls and set them out to freeze. When the ice on each is 5 to 10 mm. thick bring in the bowls to a warm place, and in a few moments the cakes will become loose. Rinse them off quickly in plenty of ice-cold water, and lay in clean and labeled dishes to melt. Now label six clean glass cylinders (graduates) and pour in the waters.

Are they colored? (Not if care has been used.)

To further prove their purity try the following tests:

Dissolve a pinch of lead acetate in 10 c. c. of water beforehand, and have some ammonia ready. In three test tubes (or small bottles) have some of the salt, alum, and copper solutions left under the ice.

1. Salt solution + lead acetate = white curd. Water from its *ice* + same = nothing or trace.

2. Alum + lead acetate = white curd. Water from its *ice* + same = nothing.

3. Copper solution + ammonia = blue color. Water from its *ice* + ammonia = nothing.

The senses of smell and taste can be applied to the others.

Would water from sea ice be salt? (No.)

How does freezing spoil ink? (Separates the coloring matter and water.)

Cider is made stronger by freezing. How? Vinegar can be concentrated by freezing. How? (Freeze, and then draw off the unfrozen part.)

Why are the bladelike crystals in frozen milk transparent? (The crystals are *water*.)

If sticks or weeds were floating in a pond would the ice be free from them? (No.)

And so we frequently find things which the crystals could not exclude, and so grew around. Sometimes these were even such strange things as drops of water or portions of a gas or vapor. These must have been entrapped in some corner, and, unable to escape, were inclosed.

(Show here, if possible, crystals inclosing drops of water, crystals of other materials, etc.)

If we find needlelike or perfect crystals surrounded by a mass of imperfect, crowded crystals (show quartz with included rutile, etc.; calcite with copper, silver, etc., or crystals of tourmaline running through rocks), which must have formed *first*? (The perfect or inclosed crystals.)

Why? (Could not have penetrated or taken perfect shape after the others were a solid mass.)

Look at the cake of separated crystals and see which seem to have formed *first*. (Alum.)

How do you know? (Copper sulphate is *on* them.)

Here is a rock with large crystals of mica among glassy quartz and shiny feldspar: Which must have formed first? (Mica.)

What, then, have we learned about crystals to-day?

1. **Mixed substances may separate** in crystallizing.
2. **Some things crystallize sooner than others.**
3. **Those crystallizing first are the most perfect and largest.**
4. **The other substances are crowded around or on these,** and hence less perfect in shape.

9. **Forms of crystals** will now be considered.

Explain to the class what is meant by the **axes** of a crystal. That to talk of crystals, of their faces and angles, it is necessary to *imagine* lines through the solid

crystal, measuring the dimensions of length, breadth, and thickness, and about which the various plain surfaces are arranged. (See Step XXVI.)

Emphasize the fact that **all axes** must **meet in the center** of the crystal. A cube will help in explaining this.

10. **Explain principal and secondary planes of symmetry.** (See Elements of Crystallography, Williams, pp. 32-34 and 44, 45.)

11. Next give each three 50-mm. (2-inch) sticks or wires (such as used in the kindergarten for "pease-work") and a little clay.

Make a clay ball the size of a small marble and thrust three of the *equal*-lengthed wires through it to represent the three axes of the *cube*.

Be sure all the angles the wires make with each other are *right* angles. Now compare the solid cube and this skeleton.

What angles do all the axes make with *each other*? (Right.)

What is the length of the axes? (All equal.)

What angles do the faces make with the axes? (Right.)

What angles do the faces make with each other? (Right.)

What shape are all the faces? (Square.)

What kind of solid angles? (*Square* corners.)

If a cubic crystal were crowded among others might it be forced to become unsymmetrical? (Yes.)

Here are some small fragments of rock salt (or of galena) which is cubical in crystallization, but crowded in great masses. Break (cleave) it in several pieces by gentle taps and then examine the solid corners. Some of the pieces are oblong and otherwise differ from *cubes*, but how does the look (**luster**) of the **three surfaces** about the solid angle compare? (Is **the same**.)

Now do not forget this, for it is important. At the close of these lessons I shall ask each one to have a collection of the specimens I give or you may get or make to illustrate the subject, so each have a neat skeleton cube, and keep the fragments of a cubic mineral with it.

Of what length are the axes? (Equal.)

So this system of crystals is called the "**monometric**" (one measure), for all the crystals have the **three axes of equal length**, and **at right angles** with each other.*

12. Yesterday we learned about the first system of crystals, called the——? (Monometric.)

Why? (All its three axes are equal in length.)

What luster did the three surfaces about the solid angles have? (The same.)

Did the crystal seem to cleave with equal ease in all three directions? (Yes.)

The second system is called the "**dimetric.**" It has other names, but this is best here.

What does *dimetric* mean? (Two-measure.)

Exactly. Now take two sticks, and, leaving one full length, cut the other exactly in two. Make a clay ball, and arrange the three axes the same as in the cube.

The dimetric system of crystals, then, has how many **axes**? (Three.)

At what **angle** with each other? (**Right.**)

Of what length? (**Two equal**, and the **vertical longer.**)

Or shorter would still give us *two* measures.

Compare it with this square prism.

Do they agree? (Yes.)

One after another tell me some of the things about our skeleton and this prism.

(Stands erect on a square base; all angles of axes or

* I have retained the old terms mono-, di-, trimetric, because descriptive in terms often used in the other sciences.

of meeting planes, right angles; solid corners, "square corners"; side- (lateral-) faces rectangles.)

Would all this be equally true if the vertical axis were shorter?—give *short*, square prisms to examine. (Yes.)

Give pieces of yellow prussiate of potash to break: Do they cleave with equal ease in three ways? (No.)

Are the three faces about a solid angle of equal luster or shine? (No.)

Hold your skeleton axes and square prism side by side, and tell me if it would be possible for the two lateral (horizontal) axes to run from the middle of one vertical *edge* to the middle of another and have all agree with this system? (Yes.)

13. Now let us make the third system. It is called the "**trimetric.**" Why? (Three-measure.)

How many axes will you need? (Three.)

What length? (Long, medium, and short.)

Keep one stick full length, and cut the second so as to have the pieces one third and two thirds. Make a clay ball, etc., as before. (Give class rectangular and rhombic prisms.) Compare your axes with those solids and see if they agree. (The class will probably be troubled by the rhombic prism, their only clew being the last question under the second system. Have it stood on the rhombic base, and they will probably see that the axis must run from *edge to edge* to be at *right angles* and of *two lengths*.)

Now each one tell me something about our trimetric system. (**Three axes, at right angles** to each other, of **three lengths**, the **bases**—top and bottom—**rectangles or rhombs**; the prisms *erect* on the base, the lateral faces similar; the solid angles may or may not be "square corners," and the cleavage (see potassium-nitrate crystals) is different in all three ways.)

(Remind the class to keep the specimens for the required collection.)

14. **Review** the three systems given.

How can the crystals vary further? (Can change the *angles* of the axis.)

Our **fourth system** of crystals is called the "**monoclinic**" (one incline), as one axis is not at right angles to *both* of the others. Make three axes, as in the trimetric, and put them through the clay ball as before. In the first three systems a knife passed straight down and exactly splitting the vertical axis would *also* split one or the other of the lateral axes. Now fix the vertical axes of our monoclinic form so that while a knife would split both vertical and lateral one way, it could not do so the other. In other words, have the vertical axis inclined a little toward *one* lateral, so that the angles will not be *right* angles. Compare this with the oblique rectangular or rhombic prisms.

Now tell me about them. (**Three axes, of three lengths, two at right angles** and the **third inclined** to one of the others; angles between the edges of three kinds, right, acute, and obtuse; cleavage differs (see mica or gypsum) in all three directions.)

15. The **fifth system** of crystals is called "**triclinic**" (three inclined), as a box crushed out of square in two ways at once. The axes are three, and all unequal. Make with sticks, as in the other systems. The forms in this are so *very* complex we will not try to study them.

Can there be *any* right angles? (No.)

Your crystals of copper sulphate must represent this.

16. The **sixth system** of crystals differs from all the others in having *four* axes. The three lateral are *equal*, at an angle of 60° with each other, and all at right angles with the vertical axis, which is longer or shorter than the others.

Make a clay ball; cut three half sticks and place them in a circle through the clay (like the spokes of a wheel); then place a whole stick (or two halves) where the axle

of the wheel would be, at right angles to the others. Compare this with the hexagonal prism.

The cleavage is basal—pieces off the end, as a stick of candy would break. This system is called the **hexagonal**, from its six sides.

You may now tell me about this system. (**Four axes, three equal, and the vertical longer or shorter**; the vertical at right angles with the other three, the sides rectangular, and the prism erect on its base. Right angles may occur over the basal edges.)

Which of the other systems does it most resemble? (Dimetric.)

There are crystals called **rhombohedral**, which belong to this section, and can be known by the equal faces about the vertical axis being in threes, and *alternate* with each other.

(Give rhombohedron, and show the class how to hold it—two sharpest angles at the extremities of the *vertical* axis.) We will not try to learn now *why* these belong to the hexagonal system. Gently break these little pieces of Iceland spar to see the beautiful cleavage.

Tell me about this rhombohedral section of the hexagonal system. (**Faces in threes** about the vertical axis, and **alternate** with each other.)

17. To further illustrate and fix these six systems read "**Crystal Orders**" in *Ethics of the Dust*, and pursue some plan like the following:

Let each pupil double his handkerchief till four thick (a piece of heavy woolen or cotton flannel is *better*), and lay it on a *level* surface before him. Give each twenty buckshot (or the little wooden balls used in the kindergarten to string), and lay them on the soft cloth, where they will not easily roll about. Each ball will represent one measure.

Lay one ball by itself. What system might this represent? (Monometric.)

Lay two balls in line. What system? (Dimetric—two-measure; $1 \times 1 \times 2$.)

Lay three balls in line. What system? (Still dimetric; $1 \times 1 \times 3$.)

Lay four balls in line. What? (Still only *two-measure*; $1 \times 1 \times 4$.)

Ruskin calls these “needle” crystals, and supposes they are built by molecules *in line*. Do we ever see such? (No; would be too fine.)

Lay two rows of two each together. What system? (Dimetric; $1 \times 2 \times 2$.)

If another four were placed on top? (Monometric; $2 \times 2 \times 2$.)

If three layers high and two square? (Dimetric; $2 \times 2 \times 3$.)

Who can tell us how to make the trimetric? (Two rows of three each, etc.)

Place four balls in a square again. How many of the others does each touch? (Two.)

See if you can make them touch *three*. (Push two between the other two.)

What figure have we now? (Rhomb, sides two and two, angles unequal.)

What system? (Trimetric; $1 \times 2 \times 2$, separated a little.)

As the balls will not lie on each other, we must omit the oblique crystals.

Lay seven in a heap and press as closely together as possible. What figure now? (Hexagon.)

What system? (Hexagonal; $3 \times 3 \times 3 \times 1$.)

18. **Planes of Symmetry.**—Would review the subject by a study of these. Proceed as follows:

Place one cube squarely on another. Turn the upper through 90° (quarter round).

Do the edges again agree? Try other faces. (Agree always.)

If a cube was sawn squarely into two short prisms would a quarter turn still make the halves coincide? The plane through which the saw passed is then a **principal plane of symmetry**.

What is its relation to a principal axis? (At right angles.)

Can other principal planes of symmetry be imagined in a cube? (Two more.)

Can you imagine a cube sawn in two similar halves which would *not* coincide by a quarter turn on each other? (Diagonally from corner to corner or from edge to edge.)

In how many ways could this be done? (On the two diagonals, and through the four edges of the upper face to the opposite edges of the lower face.)

How far must you turn these halves to have a cube again? (Halfway round, or 180° .)

Can you locate the axes—"secondary" they are called—which will be *perpendicular* to these secondary planes? (Edge to edge.)

How about their length? (All the same.)

How many planes of symmetry has the monometric system? (Three principal and six secondary.)

How many for the dimetric? (One principal and four secondary.)

How many for the hexagonal? (One principal and six secondary.)

How many for the trimetric? (No principal, three secondary at right angles.)

How many for the monoclinic? (Only one secondary plane.)

(I am fully aware of the difficulties in *imagining* these planes and perpendicular axes, but also know the beneficial effects of this mental discipline, and that such ideas will bear a rich fruitage in after years when solid geometry, etc., is taken up, to say nothing of their utility in the study of crystals and minerals.)

19. For this lesson introduce as many models and perfect crystals as can be gathered to discuss with the class. These should include such forms as the octahedron and dodecahedron in the monometric; octahedron or prism with pyramidal end in the dimetric, trimetric, and monoclinic; and six-sided prisms with six-sided pyramids (quartz), three-sided (tourmaline), and rhombs (calcite, etc.).

Gather the class about you, help them to classify each specimen in its system and give a reason for their decision, and lead them to see that, no matter how the corners or edges of a crystal are absent or replaced, it **remains true to its system unless you change either axes or angles.**

It may be suggested that it would be well here to provide potatoes, chalk, or paraffin to cut crystals from and test the matter. I have tried it in various ways and found it *beyond* the children. Have had better success modeling in clay, and it may be well for the class to replace such of the solid forms of Step XXVI as are missing. Beyond this I would not attempt to go.

Nothing now remains but to have the class bring in their collection of crystals and models for inspection and correction.

These should be arranged by each in a box and properly labeled, as they will form a valuable aid in future work, and are worthy of a place in any collection of minerals.

Next Step XXXVII—Minerals.

STEP XXXVII.—MINERALS.

So far—through Pebbles and Sharp Stones—there has been nothing said as to *kinds* of stones. In crystals this difference began to appear, and now that color, form, and crystallization have prepared the way for intelligent and correct perception, the pupil is ready to consider the varying kinds of stones. All stones are either *minerals* or *rocks*.

For these lessons we choose first the component parts (minerals) of which the aggregations called *rocks* are formed.

In the simple *sorting* of metals, minerals, and rocks the only object was for the child to *handle* and *see*.

Beginning with pebbles, and aiming at a gradually increasing demand on the mental and manual powers of the pupil, we have taken up Sharp Stones, Study of Metals, Molecules, and Crystallization.

In these studies of the minerals I consider the exercise of the judgment of the highest importance. Try by all possible means to train each member of the class to scorn aid from the teacher or from each other.

Object of the Study of Minerals.—This is briefly :

A review of the past by its application.

The exercise of the power of decision.

A knowledge of the properties of minerals in general.

An acquaintance with fifty important and typical minerals.

Preparation for the study of rocks.

Time needed.—About thirty lessons of thirty minutes each, besides the field excursions.

Material and its Cost.—In selecting this I have recognized the unconscious element in mental development, and, while bringing before the pupil as many points regarding minerals as I could, have also sought that the material should be representative of all important classes of minerals, and arranged in scientific order. Experience has shown that when the time came (in chemistry, blow-pipe analysis, and mineralogy) the pupil has usually recognized the order and system in the fifty minerals he formerly studied, and been greatly aided, although at the time not a word was said to him.

The following list has been long in use in my classes and proved very satisfactory. In it the aim has been to

1. Represent the principal classes.
2. Illustrate the properties of minerals.
3. Show the important minerals which compose rocks.
4. Include crystals of the different systems.
5. Be *cheap*. This to consist not in *poor* material, but in the careful selection, as far as possible, of the common and easily obtained instead of the rare and, in consequence, costly. After each mineral I have given some of the reasons why chosen, and *italicised* the characteristic points.

LIST OF MINERALS TO USE.

1. Native copper—(*color* and element). *Malleable*.
2. Sulphur—brimstone. (*Color* and element; *odor* when burned; *electric* with friction.) Used to make matches.
3. Graphite—(element; *streak*; *hardness of 1*). Used for pencils and crucibles.
4. Cleavable galena—(*color*; cleavage; *crystalline form*). Ore of lead.

5. Massive pyrite—(*color; hardness of 7; "fool's gold"*; sulphide of iron). Little use.

6. Sphalerite—(*resinous luster; color*). Ore of zinc.

7. Cleavable halite—(*taste; hardness of 2*). Chloride; crystalline form.

8. Cleavable fluorite—(*hardness of 4; octahedral cleavage*).

9. Magnetite—(*magnetic oxide of iron*). Valuable iron ore.

10. Massive hematite—(*red streak; oxide of iron*). Valuable iron ore.

11. Specular hematite—(*luster; iron ore*).

12. Botryoidal or fibrous limonite—(*brown streak; iron ore*).

13. Corundum—(*hardness of 9; tough*). One source of aluminium.

14. Quartz crystal—(*form; luster; hardness of 7*). Cut for "Alaska diamonds" and other cheap jewelry.

15. Smoky quartz—(*color; lack of cleavage*).

16. Agate—(*bands and origin*). Cut for ornamental work.

17. Flint—(*translucent quartz*). Indian arrow tips and ancient knives.

18. Chalcedony, botryoidal—(*form; hardness of 7*).

19. Jasper—(*opaque, red, yellow, etc.; quartz*). Uses same as flint.

20. Opal—(*luster and soft form of quartz*).

21. Augite crystal—(*form; important basic silicate*). *Short crystals, not associated with quartz.*

22. Massive hornblende—(*important acidic silicate*). *Long crystals, found with quartz.*

23. Bladed hornblende—(*form*).

24. Asbestos—(*fibrous hornblende*).

25. Topaz crystal—(*rhombic prism; hardness of 8*).

26. Garnet crystal—(*form*).

27. Chrysolite—(rock constituent). *Glassy and cleavable.*
28. Epidote—(color and rock constituent). *Peculiar green.*
29. Magnetited muscovite—(important; *cleavage*; and inclosure of magnetite). Used in stoves, etc.
30. Biotite—(*black*, basic mica).
31. Orthoclase cleavage fragment—(very important feldspar and rock former; *hardness of 6 and cleavage*).
32. Orthoclase crystal.
33. Cleavage oligoclase—(important triclinic feldspar, showing characteristic *striations*).
34. Cleavage labradorite—(another of the important feldspars; *color*; *striations*).
35. Tourmaline crystal—(*form*).
36. Talc—(*hardness of 1*; luster; *feel*; flexible).
37. Serpentine—(*color* and importance).
38. Kaolinite—(china clay; *odor* when moist).
39. Chlorite—(*color*; important rock former).
40. Apatite—(*hardness of 5*; *color*).
41. Cleavable barite—(*high specific gravity*).
42. Massive gypsum—(important rock, and used for plaster, etc.).
43. Gypsum (selenite) crystal—(*form* and *cleavage*).
44. Clear calcite rhombs—(*form*; *hardness of 3*; cleavage and *double refraction*).
45. Oölite—(*structure*; effervesces with acid).
46. Chalk—(*earthy*; form of calcite).
47. Cleavable dolomite—(angles; cleavage and to compare with calcite; *hardness of 3½ to 4*).
48. Cleavable siderite—(*form* and ore of iron).
49. Malachite—(*color* and ore of copper). Valuable for ornamental work.
50. Anthracite—(hard coal). Useful to burn.

Having decided on the above list, or such modifications of it as experience or peculiar circumstances may direct, the next thing to consider is

WHERE AND HOW TO PROCURE THESE MINERALS.

Some of the "sorting" specimens of Step VIII will do.

My practice has been to look about me and gather such material as I could, then order the rest. As to this, see suggestions in Steps VIII and XIV.

Away from a large city, where such a variety of material is used in manufacture, and especially if the teacher is not familiar with minerals, I should order the whole list, as the few one can pick up will add but a trifle to the expense. Order some time ahead, and have them come *as freight*.

The cost for thirty sets of fifty each will be about thirty dollars, as such material is now abundant.*

Boxes to store them in will be needed. The empty cigar boxes at a dealer's can not be used again by him, and should cost nothing, or but a trifle. Get fifty of these of the medium (fifty-cigar) size. Get some neat, gummed labels and place them on the ends, and pile the boxes in order (1 to 50) on the shelves of some closet. The teacher or her delegated pupil can then at a moment's notice get any needed specimen. As you put in the specimens, wrap any small fragments there may be in a paper and lay in one end, as they will be needed.

Boxes and Trays for the Class.—Those of Step III will do, although each box should hold twenty-five trays, and have a cover.

* The author will cheerfully give information as to the cheapest and best sources of supply in answer to any one addressing him by letter (at Urbana, Ill.).

I have had strong cardboard boxes 12 inches square and 2 inches deep made to hold twenty-five neat green covered trays $2\frac{1}{4} \times 2\frac{1}{4}$ inches square and half an inch deep. The boxes had the corners strengthened with *cloth*, and were covered with a bronze paper, which did not show scratches and dirt. They cost five dollars per hundred for the boxes, and five dollars per thousand for the trays. A smaller quantity might cost a trifle more.

Blowpipes and **clean charcoal** will be needed to encourage energetic work.

Streak plates of unglazed tile, bits of *sheet copper* and *window glass*, small *hammers*, etc., are already provided for in Step III, and the other things needed can be brought by the pupil.

Directions for the Pupil.—As so much of the value of these lessons depends on individual work, I had the following little guide printed in 1881 and loaned it to each pupil to work by. Slightly modified, as experience has shown wise, it is as follows :

HOW TO STUDY MINERALS.

All stones are either minerals or rocks.

A mineral is the same all through, like chalk or alum ; while a rock is like fruit cake or nut candy, being made of several things put together.

For study you will need :

1. A steel knife or small, fine file, magnetized by rubbing it on a magnet until it picks up fine iron filings.

2. A pocket magnifier.

3. A piece of window glass.

4. A piece of sheet copper.

5. A "streak plate" of unglazed porcelain, tile, or scythe stone.

6. Small hammer, and piece of iron to pound on.

7. Notebook and pencil.

First select the *mineral* you wish to study, and then follow this

ORDER OF WORK.

Observe and write in your notebook :

1. **The Color.** This may be *metallic* and

Copper red,	Silver white,
Bronze yellow,	Lead gray,
Brass yellow,	Iron black,
Gold yellow,	Steel gray,

Or *unmetallic*, and some shade of

- White (snow, reddish, yellowish, or greenish),
- Gray (bluish, smoke, pearl, greenish, or ash),
- Black (velvet, greenish, bluish, grayish),
- Blue (violet, sky, or indigo),
- Green (emerald, olive, grass, yellowish, or blackish),
- Yellow (sulphur, straw, wax, ocher, honey, orange),
- Red (scarlet, blood, flesh, brick, rose, cherry),
- Brown (hair, chestnut, reddish, yellowish, or wood).

2. **The mark** which a pencil leaves on a slate is its "**streak**," and when sharpened its powder is called the "**streak powder**."

A lead-pencil mark on paper or chalk on the black-board are other illustrations of the same thing. Now get the streak and streak powder of your specimen and notice its *color*, and whether *shining* or *dull*, *metallic* or *unmetallic*.

3. **The Hardness.** A few trials will show you that minerals differ in the ease with which you can get their "streak," some marking your plate easily, like chalk or a pencil, others less easily, like copper; while some, as flint, instead of giving a streak, *scratch* your plate, and, on trying, you find you can not cut or file them; they are too "hard." Now, the reason of this is that the molecules or little grains of those we call "hard" are fastened to each other more tightly than those of others which we call "soft."

When you rub a mineral on one *harder* than itself it leaves a streak, but when on one *softer* it scratches it; just as the slate pencil left a mark on the slate, but the slate would scratch the pencil.

This hardness is a *very* important point about a mineral, and the following table is what we compare others with, and is called the

SCALE OF HARDNESS.

(1) *Talc*; can be scratched by the thumb nail.

(2) *Rock salt*; cuts easily, but will not scratch copper.

(3) *Calcspars*; cuts harder than "2," and scratches copper a little.

(4) *Fluorspar*; hard to cut; scratches copper easily.

(5) *Apatite*; scratches "3" easily and "4" a little; will *not* scratch glass.

(6) *Feldspar*; can hardly be cut, and scratches glass a little.

(7) *Quartz*; can not be cut at all; scratches glass easily.

(8) *Topaz*; scratches "6" easily and "7" a little.

(9) *Corundum*; scratches "7" easily.

(10) *Diamond*; hardest of all.

Test such of these minerals as you can, and then, remembering how your specimen acted when getting the streak, test it with knife or file, glass and copper, till you decide which number in the scale it is most like, and write that for its *hardness*. Thus, if it gave a streak easily, but only scratches copper a little, its hardness is "3"; if it scratched your streak plate and glass *easily*, it is "7," and may be "8" or "9."

4. **Is it magnetic?** Test this by seeing if your magnetized knife will pick up the streak powder.

5. **Diaphaneity** (letting light pass through). Look at a thin edge or piece and decide whether it is

1. **Transparent**—can read through it; like glass or rock crystal.

2. **Semitransparent**—can see indistinctly; smoked glass, rock salt.

3. **Translucent**—light comes through, but can see nothing; lump sugar, porcelain.

4. **Opaque**—no light; as coal or iron.

6. **Luster**, or shine of the surface. This depends on how the light is reflected, and may be

Metallic, like metals or galena.

Vitreous, like glass.

Resinous, as rosin.

Pearly, like a pearl.

Silky, when in threads, and bright.

When a mineral has no luster it is said to be *dull*.

7. **Tenacity**. Pound a piece gently with your hammer, or cut with a knife, and decide which of the following it is most like:

Brittle, breaks in pieces easily—galena or quartz.

Tough, hard to break—corundum.

Malleable, flattens without breaking—copper.

Secatile, can be cut into layers or shavings—mica, lead.

8. **Cleavage**, or the way it breaks. This you will observe when finding the tenacity, and is

Perfect when some (at least) of the pieces are regular in shape and have smooth faces, like galena, calcspar, or rock salt.

Hackly, when the surface is rough and sharp to the touch.

Conchoidal, or shell-like, when breaking in rounded hollows and elevations.

9. **Structure**. If the cleavage is more or less perfect it is because the piece you broke was made up of smaller parts put together in some particular way, and this *way* is the *structure*. It is

Fibrous, when threadlike. These fibers are

Parallel, when side by side, or

Radiated, when running out from one point.

Lamellar, when in plates or layers, and

Micaceous, when these leaves are very thin and elastic.

Coarse granular, when composed of large grains.

Fine granular, when of fine grains.

Oölitic, when made of little egg-shaped grains cemented together.

Amorphous, when the kind of parts can not be seen.

10. **Crystals.** If your specimen or any of the pieces are regular in form, count the number of sides around the crystal and the number and shape of the faces forming the end. If it is a fragment, see whether the *cleavage* is equally perfect in all directions, or only in one or two ways, and what kind of *angles* you find.

You will now be ready to decide which of the six systems of crystals it belongs to.

Some of the simplest ways of knowing each system are as follows :

Isometric. Groups of four or eight similar planes about each *cubic axis*, and three or six similar planes about each *octahedral axis*. Cleavage *equal* in all three directions.

Dimetric. Groups of four or eight similar planes about the ends of the *vertical axis* only. Basal cleavage differs from the other two.

Trimetric. Prisms are *rhombic*. No two cleavages alike.

Monoclinic. The group of planes about any axis will be *unlike* in shape. Right angles found only over the edges around the crystal. Cleavage differs in all three ways.

Triclinic. No angle of 90°.

Hexagonal. Groups of three, six, or twelve similar planes about the ends of the vertical axis.

Tell, if you can, what minerals the crystal has grown among.

If the crystal has any substances inside of it, tell how they look.

11. **Microscope.** See if it shows you any lines or anything else the eye could not see.

12. **Feeling.** Has it a *soapy* or *greasy* feeling? Is it *light*, medium, or heavy?

13. **Specific gravity.** This more exact way of finding the relative weights of minerals, which is so important, is done as follows:

(1) Weigh a piece of the pure and dry mineral in the air—say 10.4 grammes.

(2) Hang by a fine wire and weigh in water—say 6.4 grammes.

(3) Subtract weight in water from weight in air— $10.4 - 6.4 = 4$ grammes.

(4) Divide weight in air by *loss* of weight in water— $\frac{10.4}{4} = 2.6$ specific gravity.

This mineral (quartz), then, is 2.6 times as heavy as an equal bulk of water, and 2.6 is called its *specific gravity*.

Find in the same way the specific gravity of five other minerals.

14. **Smell.** Has it any? Breathe on it, and see.

15. Has it **taste**?

16. **Acid.** Sprinkle some of the powder in a drop or two of acid on your glass plate and see if it

Effervesces (bubbles come off).

Dissolves, all or in part; and, if so,

Of what color is the solution?

17. If your own, gum a number in some hollow of the specimen. Then write the number in a little notebook, and after it the name, if known, and where it came from. Then place in your cabinet.

BLOWPIPE WORK.

Much can be found out about a mineral by this simple tool. One costing twenty cents will do. You also need an alcohol lamp (or gas), a piece of firm charcoal, pincers, a little red litmus paper, and little labeled bottles with *pure* soda. Do not try to heat a piece of mineral larger than a *pin head*. Always use a side of the coal showing the rings. Others will *snap*. Scrape a clean place for each new test. Proceed as follows:

1. Heat a piece of the mineral strongly (on coal). If it *burns*, note the *color* of the flame and the *odor*. If it *melts*, does it *smoke*? Is there any colored *coating* left on the coal? Does it *glow*, or change in any way if it neither burns nor melts?

2. Is the piece *magnetic*, *malleable*, or *brittle* after heating?

3. Laid on a bit of wet red litmus, does it turn the paper blue?

4. Mix equal parts of pure soda and powdered mineral. Fuse strongly, and place on wet acetate-of-lead paper to test for *sulphur* (black).

5. After the sulphur test, crush the mass on the lead paper and wash in a little dish. When dry, look for *iron* with the magnet, and for other metals with the lens.

Preparation of the Teacher.—Much will already have been gained in the ordering and gathering of the material and putting it away.

Books to consult will be needed. Those most helpful to me have been Dana's Manual of Mineralogy and Lithology; Crosby's Common Minerals and Rocks, edition of 1887; and Winchell's Geological Excursions.

As in the molecule lessons, so here, I would advise the teacher to call one or two friends or bright pupils to aid in the work of getting and arranging the material, and in making that preparatory trial of a series of lessons

which so lightens the class work and at the same time adds to its efficiency.

A notebook of not less than sixty pages, and opening at the *end*, will be needed. The easiest kind to get, and at the same time the best, is one ruled with money columns, and having not less than twenty lines to a page. The paper should be tough, and take a pencil-mark well.

A red-rimmed label on the cover (be sure it opens so that the broad heading space on each double page is at the *top*) is easier seen than writing on the brown manilla cardboard. As this book is to be a model for the class, place the notes and suggestions so helpful to the teacher on the last pages, and begin it as follows :

First page: Name of lessons and when begun (and finished finally). Second and third pages: head with

HOW TO STUDY MINERALS.

Read the guide, and compare with the following fragments :

Copper (sheet).	Quartz.
Galena.	Orthoclase.
Rock salt.	Magnetite.
Mica.	Sulphur.
Talc.	Asbestos.
Calcite.	Corundum.
Fluorspar.	

These fragments should be taken from the "sorting" materials of Step VIII, or from the bits too small to use as specimens for class work. Compare the little guide and these specimens, which will sufficiently illustrate the sixteen points. Keep no notes.

Fourth page: Head it with the *first mineral* and its *locality*; and along the left-hand side write on successive lines the sixteen points to be determined, adding the word "differences" after "acid."

Head the following forty-nine pages with the succeed-

ing minerals in the list; under each, to the left of the date lines, place the sixteen points to be noted; abbreviating after the first few pages to Col., Str., H., Mag., Dia., Lus., Ten., Clea., Struc., Xs, Mic., Feel., Sp. gr., etc., to Diffs. Then, in order, determine each point about the mineral in hand, and write in pencil the decision on the proper line. The first (native copper from Lake Superior) will, when done, look as follows:

NATIVE COPPER—LAKE SUPERIOR.

Color,	Copper red.
Streak,	Same, and metallic.
Hardness,	2½.
Magnet,	0.
Diaphan.,	Opaque.
Luster,	Metallic.
Tenacity,	Malleable.
Cleavage,	0.
Structure,	0.
Crystals,	0.
Microscope,	0.
Feeling,	0.
Sp. gr.,	8.80.
Smell,	0.
Taste,	0.
Acid,	0.
Differences.	

The differences, which are such a helpful feature of Dana's book, are to be left till the whole fifty minerals have been studied, when the class can unite in the *very* helpful exercise of deciding in what respect the mineral in hand *differs from all the other fifty*.

Uses might be added if time permits, but I should let the pupils look it up alone, and then correct in a general exercise.

Now let the teacher and companions compare "copper" with the notes given, and then each unaided work out the next four specimens. To test their results, compare with Dana, and correct if need be. A few difficulties may arise from the condensed directions of the guide.

1. **Color.** Of this little need be said.

2. **Streak.** Will explain itself. Make a series, as advised in metals.

3. **Hardness.** Teach the pupils always to try the glass *first*, copper next, and finger nail last, which will save trouble.

Also caution against injuring the edges of a crystal or nice specimen with the knife or file. For such tests choose some *broken or unimportant* corner or surface.

4. **Magnet.** Use the powder made in getting the streak, both to save material and time. Some pupils have no idea of economy of either, and it is a needed lesson. *One* test with the knife over a bit of white paper should answer for "streak," "hardness," "magnet," and, in the majority of cases, all questions in "structure."

5. **Diaphaneity.** Always choose *thin* edges or pieces.

6. **Luster.** Scaly minerals usually have a *pearly* luster.

7. **Tenacity.** In getting the hardness or streak nearly all points under this head will be observed. Still, it is well to take some fragment, and, having broken it by gentle taps with a light hammer, examine the fragments with the microscope for the cleavage and crystalline form disclosed. Caution the class against breaking up *crystals* or *large* specimens, and, to remove all temptations, give a little fragment of each, if possible, for them to use in all testing which involves injury to the large specimens.

8. **Cleavage** will be seen from the large specimens, which will usually be fragments, and from the breaking when finding tenacity. If it is an *unbroken crystal*,

nothing can be told unless a fragment can be had. Distinguish between the smooth face a crystal may have taken in *growing* from the similar surface due to *cleavage*. Quartz, for example, grows in smooth-faced crystals, but has *no* cleavage, breaking like glass. "Hackly" and "conchoidal" are not strictly "cleavage," but "fracture," still the distinction is not worth making here.

9. **Structure.** This is mainly the result of crystals being crowded together when growing, but may be from different causes, as in oölite, where the "similar parts" (as I have called them, to include all) are not crystals.

Of course the structure of a mineral which does not break (copper) can not be told. It is *amorphous* when (like opal or coal) nothing can be seen.

10. **Crystals.** Omit the "systems" if too hard, as they frequently will be, although I believe more can be done than is usually supposed if form has been well taught. Have them *drawn* if the class be able.

11. **Microscope.** Each child should be encouraged to get a small pocket lens. If purchased by one of the class at dozen rates they are very cheap (twenty-five to thirty cents for three-quarter-inch lens in rubber holder).

12. **Feeling.** Let each child exercise its judgment as regards comparative *weight*, calling those about like quartz, "light"; those like hematite, "medium"; and those like galena, "heavy."

13. **Specific gravity.** Scales and fine weights will be needed for this work, which I introduce here not only for the mineral work, but to give the child a *practical* acquaintance with the metric system of weights. Metric lengths and volume have been already given (Steps XXI, XXVI, and XXXI), and weight has been delayed only till a suitable time came, when it would be of real *use*.

Scales and weights are not as expensive as might be thought. A "prescription balance," having an extra weighted hook to replace one of the pans, and costing

under five dollars, will do as well for the pupils as a twenty-dollar balance (made expressly for such work), and can be used for other things.

The weights will be extra. Brass ones from twenty grammes to half a centigramme can be had for eighty cents; or buy the brass weights from twenty grammes to one decigramme, and twenty-five cents' worth of aluminum wire. When buying, have the wire accurately weighed in *milligrammes*. Measure the whole piece in millimetres, and estimate how many millimetres in length for five-, two-, one-, and a half-centigramme weights, and with strong scissors cut off as exactly as possible bits of the lengths required, cutting two of the two-centigramme weights to each set of the others.

Bend the five-centigramme piece with three angles, one angle to each of the *two* two-centigramme bits needed, and leave the one-centigramme and half-centigramme bits straight. The quarter's worth of wire will make quite a number of sets of these weights, and I would advise cutting it all up while at it, as such weights are apt to be lost. Use the pincers of Step XXV to pick up the weights, which must never be put down except in *scale pan* or *box*. Five such scales and sets of weights will do quite well for a class of thirty. Use fine copper wire to hang the specimen by, as it is much easier to fasten around and adjust than thread. I would weigh several specimens with the class, and let them figure out the results with you before the pupils try, and when they begin let them verify one or two of those results first. If these precautions are observed the class will do excellent work from the start.

14. **Smell.** Tests on hot iron should be made out of school, unless the class has a room to itself or meets after the rest of the pupils have gone home.

15. **Taste.** Few minerals have taste, but if the halite (rock salt) is valued much it should be taken away after

testing, as many children seem to crave salt, and "taste" till but little is left.

16. **Acid.** I have had no end of trouble from pupils *reversing* the directions. *Never* put acid on a mineral, but always put small bits of mineral *in the acid*, when they can be watched and results noted. Look out for the *clothes*, or acid may ruin them.

With specimens, boxes and trays, little books of directions, acid, etc., ready, and the personal acquaintance with the material derived from the foregoing study of the fifty specimens to be given the pupil, the teacher is now prepared for class work.

THE LESSONS.

There will be two stages in these: 1, to compare *terms* with wisely chosen *material*; 2, to compare *minerals* with *descriptions*.

LESSON 1.—**Give** each pupil a **box, 25 trays**, a streak plate, bit of sheet copper, bit of unscratched window glass, a notebook, and a copy of How to Study Minerals. Let the class prepare blank labels about $1\frac{1}{2} \times 2$ inches (*narrow strips get displaced, and those too large for the trays look untidy*), and neatly copy after the teacher while he writes on the board the *names* and *localities* of the thirteen fragments to use in explaining the guide and first two pages of notebook. Place these labels in the trays, beginning at the upper left-hand corner, and when the first row of five boxes is done return to the left-hand tray of the second row, as in reading a second line.

Now let the class compare their labels while you read the list aloud, then give out the thirteen fragments, being *sure* each pupil has one, as they are to be held accountable for everything given. Replace the covers on the boxes, and let each gum a neat label on the upper left-hand corner of the box cover and write his or her name plainly in ink.

Telling the class to carefully read the guidebook before the next lesson, gather up the boxes by rows, or in some way they can be easily returned, and put where no one can disturb them. Appoint some reliable pupil (or have the class choose a "committee") to see about lenses, also notebooks like yours. Ask each to bring a broken-bladed knife or bit of old file.

LESSON 2.—Distribute the boxes. Remove the covers and put under the boxes, where they will be out of the way and not get torn. Let one pupil after another read a paragraph of the guide, and after each reading explain or illustrate from the specimens in the box, in *every case* letting the pupils try to discover the specimens in point, and *telling* only as a last resort. For example, John reads, "The color may be metallic or unmetallic."

Tell me, John, which are metallic? ("Copper, galena, magnetite, and corundum.")

Jane, which of the metallic colors have we? ("Copper red, lead gray, and iron black.")

Alice may read, "Or unmetallic, and some shade of white."

You may tell me which white minerals we have. ("Rock salt, calcite, and perhaps others.")

Are they pure white, Samuel?

Now will come the puzzle: Shall *transparent* mica be called "white," or whatever tinge it has? I have always said "Yes," just as we speak of "white" glass to *distinguish* it from "colored."

Mary, have we any "grays"? So proceed.

When the class comes to *streak*, let them mark (or try to mark) a row of the thirteen streaks on the tile, and then discuss them.

Hardness. After the caution given before (see Preparation of Teacher) let the class try cutting the specimens given in the scale from 1 to 9, and observe the color of *streak powder*, *magnetism*, and *tenacity* as it is done.

Explain to them that if the copper is scratched by a mineral hard enough to scratch glass, time is lost and the copper spoiled to no purpose, and so the regular order should be, first, the *nail*; if that fails, try glass; not scratching glass, try the copper. Following this plan, let the class all together go over the thirteen specimens and determine the hardness. In practice, the knife should be the main reliance, and each pupil should learn to use it in such a way as to give exact results. Do not *whittle* (as a stick), but, holding the specimen firmly between the thumb and finger of the left hand, place it against the thumb of the right and cut *toward* you, as in pointing a pencil.

Spelling lessons during these days should be drawn from the guide.

LESSON 3.—*Diaphaneity* need not take long.

Luster is also easy.

Tenacity. The cutting will answer nearly all these points; others can be found with the hammer.

Cleavage will be quickly understood.

Structure has already been explained.

Five at least of the thirteen test specimens will show the crystalline form, and the teacher must decide what is to be done, and see that it is understood.

The lens should have been used all along.

Feeling will probably complete this lesson.

LESSON 4.—**Specific gravity** has already been spoken of. A word as to the *method* of weighing and handling of the weights. We will verify the specific gravity of the quartz given in the guide.

1. Dust off the scale and see that it balances.

2. Place (never *drop*) a 20-gramme weight in left-hand pan, and hang a piece of quartz by a fine wire from the right, at such a height as to be an inch above the bottom of a dry tumbler placed below. (Should it raise the 20-gramme weight, choose a lighter piece of mineral.)

3. Steady the left scale pan with a finger while the 20-gramme weight is put back in the box and 10 grammes put in. (Not enough.)

4. Gently add 5-gramme weight. (Too light.)

5. Add 2-gramme weight. (Too heavy.)

6. Remove 2-gramme and put in 1-gramme weight. (Too heavy.)

7. Remove 1-gramme and put in 5-decigramme weight. (Too heavy.)

8. Remove 5-decigramme and put in 2-decigramme weight. (Too light.)

9. Add 2-decigramme weight. (Too heavy.)

10. Remove 2-decigramme and add 1-decigramme weight. (Too light.)

11. Add 5-centigramme weight. (Too heavy.)

12. Remove 5-centigramme and put in 2-centigramme weight. (Too light.)

13. Add 2-centigramme weight. (Just right.)

14. Count up weights, writing each in a column to add.

10 grammes + 5 grammes + .3 + .04 = 15.34 grammes.
(Weight in air.)

15. Record in notebook.

Notice in the above weighing that the adding and reducing of weights has always been by *one half*, as nearly as the weights would permit. If too heavy (20 grammes), it was made one half *less* (10 grammes). Being too light (10 grammes), one half (5 grammes) was added.

16. Fill the tumbler with cold water till the specimen hangs entirely below the surface and still clear of the bottom. The 15.34 grammes will now be too much, as the immersion of the quartz has raised its own bulk of water, and is thereby buoyed up by the exact weight of the water raised.

17. Return all but the 10-g. weight to the box. (Too heavy.)

18. Remove 10-g. and put in 5-g. weight. (Too light.)
19. Add 2 g. (Too light.)
20. Add 2 g. more. (Too light.)
21. Add 5 dg. (1 g. would make 10 dg., which we *know* is too much). (Too heavy.)
22. Remove 5 dg. and put in 2 dg. (Too light.)
23. Add 2 dg. (Too light.)
24. Add 5 cg. (Too heavy.)
25. Remove 5-cg. and put in 2-cg. weight. (Too light.)
26. Add 2 cg. (Just right.)
27. Count up weights: $5 + 2 + 2 + .2 + .2 + .02 + .02$ g. = 9.44 g., the weight of mineral which the water did *not* buoy up.

28. How much did it buoy up? (Evidently the difference between the dry weight and the weight in water— $15.34 - 9.44 = 5.90$ g.)

Now this 5.9 g. is the weight of a bulk of *water* exactly equal to our piece of *quartz*, and to find how the weight of quartz compares with water (which is the standard for liquids and solids) we *divide the weight in air by its loss of weight in water*— $15.34 \div 5.9 = 2.6$, the specific gravity of quartz.

Smell, taste, and acid require no further notice, except that if small fragments of mineral are dropped *into* the acid much better and neater results will be had than from the slovenly practice pupils seem to prefer of putting acid *on* the specimen.

LESSON 5.—Before the class meets let some pupil put the names and localities of the first twenty-five minerals on the board for the class to write such as are not already written. When the class is ready for work, have them return the test fragment of mica (as not needed in this set), and arrange the labels in order, putting those needed in the next box under the twenty-fifth tray, and the calcite, etc., belonging in the second set (but needed here for testing hardness) in the first tray.

Absentees cause much trouble, and always, in giving out specimens, provide for them by the teacher or some friend of the absentee taking their boxes and doing for them whatever the class does. Of course this *is* a loss to the pupil, but beyond a cordial invitation for such to come for private direction, I should advise that the work move steadily *on*. One *important* result of systematic and progressive science work will be found in its reducing absenteeism to the *strictly unavoidable* limit. The child will be so interested that, however distasteful other work may be, he will endure it for the pleasures of the science lesson. At least with me it has proved a leaven to lighten the whole school work.

Put the model for the fourth page of notebook on the board to be copied while the distribution goes on.

Distribute the twenty-five specimens. Be *sure* each child present and each absentee has a full set in addition to the extra specimens of the scale of hardness, the copper, glass, tile, and guide. Read the heading and sixteen points of fourth page to see that all agree. **Study first specimen** with the class.

Class write heading and points of second and third minerals, and compare by public reading.

Class *independently* study and write neat notes on second and third.

Change notebook and publicly criticise and correct.

Collect notebooks for examination by teacher as to accuracy and neatness.

Six to thirteen lessons will be now spent in work by the pupils, and the teacher has nothing to do but to say "No" to those who want too much help. Encourage those "in the Valley of Indecision," and amid the bustle of work keep the pupils from interfering with or aiding each other. The thorough preparation will now bear fruit.

Prompt, accurate work. Encourage by the promise of a reward for those who finish in time, which reward may be anything the teacher chooses, but with me has taken the helpful shape of blowpipe work, of which more will be said in the proper place.

Punishment for the lazy and indifferent, always to be found, will be the direct result of such conduct—they simply punish themselves by losing the benefits from the lessons, and nothing more is needed.

The class will be somewhat hampered by the spelling and new terms. This can be *helped* by spelling, as suggested in Lesson 3. The pupils will only do two or three minerals the first day of this work, and perhaps rise to five at the last. Never *hurry* them; simply see that *steady, deliberate* use of the time is made, as another of the many valuable lessons included in this fertile subject.

Teacher examine and mark errors (in blue pencil) as fast as the pupils finish the twenty-five specimens.

Pupils correct errors. After marking, let the pupil find his mistakes and correct them. Some misunderstanding will here be discovered, and can be explained.

Pupils mix and replace. Errors corrected, let each take his specimens and put them in a *mixed* pile on the box cover, and then return to the proper labels. This sorting is a great aid. If he fails in even one mineral let him repeat.

Pupils mix and exchange. When two pupils (not seated too near each other) have shown their ability to recognize their own specimens let each place minerals in a mixed pile and exchange boxes, to sort those they have not seen. Encourage the reference to notes and use of any known tests in doing this. Suppose the pupil hesitates between hematite or limonite. He looks, and finds the first has a *red* streak, and the second a *brown*. Taking his streak plate, the question is at once

settled. When the minerals are back in their places, let the two (in quiet tones) look the results over together, understanding that any objection is to be backed up by a reason and proof. Here (not sooner) is a good place to introduce the use of **Dana's Manual** as a reference book. Encourage (by the discount the teacher can get) the pupils able to *own* the book, which stands unequalled as a clear and concise work. One of the most helpful things a teacher can do (as soon as the pupil can read, or *sooner* by example) is to **train in the skillful use of books**. It is not best, in my judgment, to attempt to remember much about things one would not trust his memory for, except to know *where* the data is to be found, and this covers very much in geography (latitude, longitude, etc.), history (dates), chemistry (atomic weights and formulæ), physics (specific gravities, data regarding expansion, etc.), mineralogy, and other subjects. If such things are *needed*, the frequent looking up and use will soon fix them; if not needed, who wants to remember them?

These bright and industrious pupils will now have completed the first stage of the work, and know more or less perfectly *how to look at* a mineral, the points of difference, etc.

The second stage should continue and fix the points of the first, and also teach the *comparing of specimens* with *written* (or printed) *descriptions*. It is difficult to do this satisfactorily with a large class working together, so advantage can be taken of the fact that some finish sooner than others to secure the *individual* work needed, in the following way:

New boxes can be given, or the first emptied and new labels put on.

How to empty.—There are some suggestions which will be of aid.

1. Pupil removes streak plate, copper (sheet), bit of glass, notebook, guide, labels, and any other property be-

longing to him or needed, and the few fragments from the test specimens which belong in the second box.

2. He presents the neatly arranged set of twenty-five specimens to the teacher for inspection. If all right, the teacher puts on the cover, and by a quick movement turns the box *upside down*. The contents are now in the *cover*.

3. Lift off the box, and gathering up the emptied trays, give them back to the pupil to arrange, while the specimens are gathered in the two hands and laid (not *thrown* or *dropped*) in a large, shallow box provided, and the pupil is given his cover again. All this takes less than thirty seconds to do, and the injury to the specimens is very slight. The subsequent sorting and putting away will be helpful to and enjoyed by the pupils.

New list on board.—This should be placed where it can remain for some time, and as follows:

No. 26. Garnet—reddish, 24-sided crystals.

No. 27. Chrysolite—greenish, glassy mineral, with *cleavage*.

No. 28. Epidote—yellowish green and opaque.

No. 29. Muscovite—splits in thin, *elastic* scales.

No. 30. Biotite—cleaves in thin, *elastic black* scales.

No. 31. Orthoclase—hardness of 6; perfect, pearly *cleavage*.

No. 32. Orthoclase crystals—angles around the crystals 90° .

No. 33. Oligoclase—hardness of 6; yellowish white; *lines* on cleavage surface.

No. 34. Labradorite—hardness of 6; *grayish*; *striations* on cleavage surface.

No. 35. Tourmaline crystals—black; 6-sided crystals.

No. 36. Talc—hardness of 1; feels soapy.

No. 37. Serpentine—hardness of 4; greenish; clay smell.

No. 38. Kaolinite—white and soft; clay smell.

No. 39. Chlorite—dark green ; soft.

No. 40. Apatite—hardness of 5 ; glassy green ; 6-sided crystal.

No. 41. Barite—white and *heavy* ; hardness of 2 to 3.

No. 42. Gypsum—hardness of 2 ; no effervescence in acid.

No. 43. Gypsum crystal—hardness of 2 ; cleavage in flexible scales.

No. 44. Calcite—Iceland spar ; laid over fine lines and turned makes them *look double*.

No. 45. Oölite (calcite)—structure oölitic.

No. 46. Chalk (calcite)—white and earthy ; effervesces in cold acid.

No. 47. Dolomite—hardness of $3\frac{1}{2}$; effervesces less freely than calcite ; rhombohedral crystals.

No. 48. Siderite—hardness of $3\frac{1}{2}$; brownish and heavy ; rhombohedral crystals.

No. 49. Malachite—beautiful green ; effervesces in acid.

No. 50. Anthracite—black ; conchoidal fracture ; burns without flame.

I have omitted the localities, which the teacher should put in, and the points given must be made to agree with the material, which will differ in some cases.

Pupils as fast as ready should head the next twenty-five pages of their notebooks, and write the sixteen points for determination as before. Also prepare labels.

The minerals are not to be given to the pupil, but selected by him. Place one or more shallow boxes or trays in light, convenient places about the room, with about five specimens of *each* of the second twenty-five minerals in every box. These 125 specimens should be mixed together, and when the pupil has his box and labels all ready let him (*alone*) at one of these mixed collections select his set of twenty-five, using the brief descriptions on the board as an aid. He should also be permitted to consult Dana if he wishes.

Boxes corrected.—When a set has been selected, bring to the teacher, who should run over the box and *remove any duplicates*. Let the pupil then return these duplicates to the mixture and try and fill the vacancies. With the little direction and limited experience at his command, I would advise calling his attention (if a second failure results) to points that will help him, as it is really quite a difficult task for *him*.

When he has selected his twenty-five different minerals help him to get the specimens to correspond with the labels, and then he can start to work and make his determinations as before; have his notes marked; correct his mistakes; and sort his own and some one else's minerals till the work can be accurately done. Now, as his reward for prompt, energetic study, will come

Blowpipe Work.—Give each pupil, as he satisfactorily completes the above, a lamp, piece of charcoal, some bits of galena the size of a pin head, a blowpipe, and the other things given on the last page of his guide, and let him take them into some corner or anteroom where the attention of the others will not be called off, to do what he can with the blowpipe.

Show (by a copy on the board) how to arrange the notes, which should *always* be kept, and which do so much to check trifling and aimless work. The following is a model of his pages after testing galena and hematite. By all means put such notes on the same page with his other determinations on the same mineral; or by a note refer to the place where these blowpipe tests are placed.

GALENA—BLOWPIPE, TESTS.

1. Melted to beautiful globule; yellow coat on coal.
2. Brittle, and looked like galena.
3. No change to red paper.
4. Paper *black* = sulphur.
5. Little flat scale of malleable lead.

HEMATITE—BLOWPIPE TESTS.

1. Red hot, but no melting.
2. Magnetic (if heated enough).
3. No change to red paper.
4. No sulphur.
5. Magnetic grains of iron.

Provide trays of named fragments for them to select from, pyrite, galena, hematite, calcite, malachite, oölite, gypsum, sulphur, siderite, anthracite, and sphalerite being best.

A little oversight may be needed, but it is a *reward*, and the only condition should be *neat* and *exact* work and notes. If they play too much or do not fulfill the above conditions, let them forfeit the privilege.

Close up this part of the work as soon as all have had a reasonable time to do the work, those finishing last having no time for blowpipe work.

Review.—Make this a general exercise, as advised in previous work, by (1) each *telling* something they have noticed ; (2) by a rapid questioning on terms, methods, and peculiarities of minerals ; (3) by describing minerals from memory, the class to tell what is described.

After this refreshing of the memory proceed to the **differences**, which his study of the whole fifty will now make in order and *very helpful*. My personal study and delight has always been to seek the *one* thing by which a particular mineral, plant, or animal is characterized, by which it can be at once known. Failing to find one, I have sought the smallest possible *combination*. Increased knowledge has often obliged me to change or modify such "earmarks," but on the whole it has proved a very helpful practice. Make this a general class exercise, letting them take turns in telling how they would distinguish some particular mineral from all the rest, the teacher adding such points as they may not have had a chance to learn.

Many of these points are italicized in the list given under Material; also some of the uses.

Return specimens in second box to the teacher, as indicated before.

Review of the whole.—Let the teacher gather, from private collections, school set, or from friends, 100 or 150 specimens of the minerals studied which the class have never examined. This will average two or three of each kind, but it will be better to have one or two of the less important and four or five of those of frequent occurrence in rocks or valuable ores.

Take four to six box covers and fill each with twenty-five trays. In the bottom of each tray (labels get mixed) mark in soft pencil numbers from 1 to 100 or 150. Now, without any attempt at order, place the new specimens in the trays. When the time comes place them in light places about the room, or pass from pupil to pupil, who should have pages in their notebooks prepared by numbers on the left-hand side of the pages corresponding to those in the boxes, and after each number they are to write what they determine the mineral in that tray to be.

Free use of notes, Dana, and any other helps they know of, should be encouraged, but they must not help one another.

When this test is completed let the pupils change notebooks, the teacher taking the minerals and naming them in order from No. 1 up, while the pupils check the mistakes.

Should time permit, it would be well for the specimens to be again given to the class, that each may correct his errors.

Material put away.—Let willing and trusted hands sort the 1,500 mixed specimens, picking out the *soft* ones first, and, as thirty of a kind are found, bring to the teacher for inspection and return to the store box.

Fragments.—Save for blowpipe work in the future.

Blowpipes, streak plates, How to Study, etc., should also be put away in labeled boxes.

Field Work and Pupils' Collections.—It is *all important* that the connection between these indoor studies and *nature* now be made. Have the class hunt up old hammers and hatchets (a "lathing" hatchet is excellent), and, led by the teacher or some competent person, explore quarries, crack bowlders, visit mines, stone yards, marble works, etc.

The specimens thus gathered, with such as the pupil may have acquired in other ways, should then be brought to some place, tickets gummed on (see Step XIV), and each set neatly numbered in ink. Opposite corresponding numbers in the notebook should now be placed (in *pencil*) what he or she determines it to be. Then, the pupil having done all he can, let the teacher revise his list, leaving blanks for all *unknown*, and in case of *rocks* naming them only as containing such and such minerals.

This will test the *teacher*; but I have never found a frank "I do not know" to weaken my influence in the least. In fact, well-taught pupils are a little distrustful of the teacher who knows *everything* and can learn no more.

A gift of some admired or unobtainable specimens will send all home happy, and be money well spent.

In conclusion I have nothing to say, as such work will speak for itself.

Next Step XLIII—Coins.

STEP XXXVIII.—ANIMALS.

THE LIFE HISTORIES OF SOME TYPES.

Object.—A general survey of animals has been had in Steps V, IX, and XI. The foundations of a knowledge of external organs and their functions has been laid in Steps XIX and XXVII, and the inter-relations of animals and their environments, with something of geographical distribution, considered in Step XXIX.

For the student or class which has done all of this work in a thorough and consecutive manner the next two steps may well be omitted, and the subject of classification taken up at once.

Experience has, however, shown that new pupils coming into a class, and irregularities of attendance due to the various accidents of health, etc., will render a review highly advantageous.

This I have cast in a shape which will have the freshness of a new subject, and still include the essentials of a review of former studies.

Time.—Spring is the best to secure material, and in graded work other classes will be using the same material about this time. There will be about forty drawings to make, but many are small and easily done, so that twenty to twenty-five lessons of thirty minutes each will easily cover the work. If, as is hoped, it can be made the basis of the drawing lessons, the step will really take but very little extra time.

The work of this step and that of the preceding (minerals) may easily be interwoven, and the drawings be be-

gun as early in the spring as material can be procured, taking whatever comes, without regard to the order, and resuming the mineral work in case animal material fails or delay is needed to watch and record the development of eggs, larvæ, etc.

Material.—Must be mostly fresh, and suggestions as to where and how to procure it will be found in previous steps of animal work.

Each student will need a drawing book or sheets of drawing paper about 8×10 inches in size, and a good pencil. Some **water color** can be used to excellent advantage. Use erasers sparingly, if at all.

I have found it possible to secure a sentiment in a class so opposed to erasures as to result in that careful examination of the object and exact and painstaking reproduction on paper which is so desirable.

Preparation.—A teacher should have made all the drawings from life and thoroughly studied the life history in each case before attempting to give the lesson, and this can best be done a year in advance. Arrangements for material must be carefully made.

THE LESSONS.

1. Have the pupils head each page of their drawing books with the name of the animal whose life history is to be more or less completely illustrated on that page—e. g., “Frog: eggs, tadpoles, adult.” This will permit the drawings to be neatly arranged on the page, even though made at different times, and also enable a pupil to keep at work, though the specimens available are not in the exact sequence of the list to follow, which is according to Dr. Emil Selenka’s classification.

2. Taking the first available material, or such as will not keep (eggs, larvæ, etc.), let the class go to work at the careful study and—to aid in this—illustration of the life histories of the selected types. Morse’s First Book in

Zoölogy* is a model for the kind of drawings to make, and for the spirit in which the work should be done.

Amœba.—Draw from personal observation under the microscope, if possible; otherwise copy from some book. Morse's First Book in Zoölogy or the Riverside Natural History will supply cuts for any copy which will have to be made.

Earthworm.—Place on a wet dish and draw from life. Eggs and young can be copied.

Starfish.—Draw from life, or dried specimen, both upper and under sides, and copy a cut of one arm with the tube feet extended.

Crayfish.—Place a live specimen in a shallow dish of water and sketch the eggs, young, and adult. Keep careful data regarding the *time* required to hatch the eggs, when young forsake the mother, etc.

Spider.—Sketch a cocoon of eggs, the young magnified, and the adult with her web. The latter may have to be copied from Morse.

Squash Bug.—Sketch eggs on squash leaf, larva, pupa, and imago.

Butterfly.—Sketch eggs on cabbage leaf (or food plant), the caterpillar after each molt, pupa, and when hatched, the imago. The latter should be sketched with the left wings upside down, and, to show this, slightly detached from the body. If color is used after the outline has been drawn with a fine-pointed pencil it will greatly add to the scientific value and attractiveness of the sketch.

It is also well to note the time in days (or hours, if short) between one form and another from the first tiny caterpillar to the imago.

Clam.—Draw the outside and inside of one valve; also of the animal, if it can be had. The latter can be copied from some good work on zoölogy.

* D. Appleton and Company.

Water Snail (operculated, gill breather).—Place in a dish of water for study, and draw eggs, young snail, and adult (when the head is out) with shell and operculum on its back.

Land Snail (air breather).—Eggs, young, and adult when head is out of the shell. Eggs and young will probably have to be copied from Morse.

Fish.—Draw from life, or, if dead, take a thin board, and, laying the fish upon it, draw the fins into position with pins and fasten. Slightly incline the board on edge, and the fish will be in excellent position to sketch in outline. Pay careful attention to the exact position and number of spines and soft rays in the fins, the position of the mouth, kind of gill covers, etc. Also detach a scale and make an enlarged drawing of its shape and structure. Copy eggs and fry from some work on zoölogy.

Frog.—Sketch newly gathered egg cluster, and make other drawings, with the dates and time, as often as changes appear in the eggs. Draw tadpole when hatched (magnified, if possible), and draw as often as any change appears till the small but perfect frog has developed. Would consult (but *not* copy) the sketches in some good work on zoölogy.

Snake.—Draw eggs, young, and adult. Be exact about the number of rows of scales over the back, and the shape of each.

Hen.—Sketch the egg and copy the internal structure of the same from Orton's Comparative Zoölogy. Sketch the young chick from life; also the hen.

This completes the list it has been found best to use. Interspersed with the drawing exercises should be such discussions of the different animals as the class may need to bring out the salient characteristics of each type. Some of the material can most easily be had in the fall term (e. g., butterfly, spider, squash bug), and in such case I

would delay the study till then, or let the pupil do it in vacation.

The next step—XXXIX—is only inserted to give opportunity to complete the autumn work of this, and may otherwise be omitted.

STEP XXXIX.—ANIMALS.

THE LIFE HISTORIES OF SOME TYPES—(*Concluded*).

Object.—The same as Step XXXVIII, which see.

Time, etc., autumn. This step is introduced at this time of the year in order that such desirable studies of types as could not be made in the spring may now be taken.

Abundant material can easily be found in the autumn for any desired number of lessons, especially on insects; but I would advise saving the time for the other science work of the year, and, having pushed the outline of Step XXXVIII to a conclusion, stop.

The work of this and the next step can well go on at the same time; perhaps best so.

The next step is XLIX—Animal Groups.

STEP XL.—FRUITS REVIEWED.

Object of this Step.—Fruits were looked at and sorted in Step I; studied more carefully and grouped in Step XVIII. One fruit was examined in detail in the Morning-Glory, Step XXIII, and the relation to distribution of the seed and uses considered in Steps XXVIII and XXXIV.

Four years will now have elapsed since Step XVIII was taken; many new pupils will have come into the classes since then, and now it may be advisable to review the subject along the lines given in Steps XVIII, XXVIII, and XXXIV. The stress should be laid on the following:

(a) **Origin** (a ripened pistil or pistils with adhering parts).

(b) **Protection** while growing (green, sour, bitter, etc.; see Step XXVIII).

(c) **Variations** in form and structure (see Step XVIII).

(d) **Modes of opening** (see Step XVIII).

(e) **Methods for self-distribution** of the seeds (see Step XXXIV).

(f) **Lures to secure aid** in seed distribution (see Steps XXVIII and XXXIV).

(g) **Modes of compelling aid** in distribution (see Steps XXVIII and XXXIV).

Time used should not exceed twenty half-hour lessons in the autumn.

Material.—The same as used in previous steps and in graded school work. That of one room can frequently be used again in some other.

Preparation of the Teacher.—Read the steps referred to above under “Object,” and arrange such work as each class may require.

Drawing and **color** work will find abundant material in connection with this step, and reduce the time needed. With the previous training the science work has given and the increased age and ability of expression by word, pencil, or brush, this should prove a very attractive and profitable piece of work. Make thorough preparation, and push the work energetically to a conclusion.

Material put away (see Step XVIII).

The next step in plant work is Corn and Beans—Classification, Step XLI,

STEP XLI.—CORN AND BEANS.

Object.—The basis of plant classification.

The unconscious comparing through the *sorting* of the earlier steps has been made more exact through the studies of metals and minerals.

The culminating work in developing the powers of exact observation and concise description begins with this step, and is continued through Steps XLV, XLVI, and XLIX.

Familiar now with *many* plants and with some insight into the meaning of their variations of form and structure, the pupil occupies a vantage ground from which to consider their relationship with each other. This new view will also make an effective preparation for what is to follow.

The Time.—About twenty lessons in the early autumn. Should it be deemed wise to give Steps XXXIX and XL, the frosts may destroy the flowers for XL unless taken in advance, and the work must be skillfully planned and XL may have to be delayed. Much of this step could go on while other work was in hand, taking a lesson in this whenever material was ready.

Material.—Little is needed. A handful each of corn, onions, oats, wheat, and rye for the monocotyledons, and beans, peas, morning-glory, melon, and turnip or radish seed for the dicotyledons. Provision must also be made for flowers with parts in threes and fives, and cannas and gladioli should be planted in the spring for the threes, and nasturtium, petunia, and morning-glory for the fives.

The preparation of the teacher is partly indicated above. Go over the step in advance, decide just what to do and when, locate and arrange for material, and then *push the work* steadily to a conclusion.

OUTLINE TO BE DEVELOPED.

- A. How do the planted seeds emerge ?
- B. How many cotyledons has each ? What other parts ?
- C. What kind of roots, multiple or tap ?
- D. The stem, as to bark, wood, pith, and branching.
- E. The leaves, as to veining, simple or compound, general outline, tip, margin, base, petiole, and arrangement.
- F. Flowers, parts in threes or fives.
- G. Seed, all germ (exalbuminous), or with food (albuminous).
- H. Grouping of all the plants in two sets, under corn and beans.

THE LESSONS.

1. **Plant** two or three **seeds** of each sort (see Material) for each member of the class. Boxes holding two or three inches of clean *sand* are best, as the plants will be neater to handle. Record the date of planting, the highest and lowest temperature each day, and, keeping the ground well watered, record the *hours* before they first show through the covering of sand.

If planted some Friday afternoon, this will be completed before the end of the next week.

2. Let the class take **notebooks** (about 10 × 16 cm. in size, and opening at the end) and head the top of successive double pages with the questions of the Outline.

On the first page record the date of planting and temperatures, list of seeds, and after each the hours for it to come up, and whether it *pushed* out (corn) or backed out

(bean). Press a specimen of each to mount and label (if the time permits and practice in such work is desired).

3. While the seeds are coming up, study question D. Give the class the sections of **stems** from Step XIII (to represent the way a bean would grow if it lived several years) and pieces of cornstalk. When complete, the proper page in the notebook will be thus :

CORN.	RESEMBLANCES.	BEAN.
(Sketch cross section of cornstalk here.)	Cylindrical stems. Hard outside. Pith. Wood.	(A sketch section of oak stem here will do for the bean.)
	DIFFERENCES.	
Smooth, green skin..	Bark.....	Rough, dark bark.
In threads.....	Wood.....	In rings.
None	Radiating lines ...	Many.
Much.....	Pith	A little in the center.
Unbranched.....	Branching	Much branched.

In all the notes keep "corn" and its allies on the left side of the page, and "bean" and allies on the right. Under "resemblances" place (in the middle of the page) all the points in which the plants are *alike*. In the blank space to either hand make such drawings as will illustrate. On the lower page place "differences," and under the word all the points observed, extending each point as may be appropriate to the heading (corn or bean) it falls under. After the pupils have *individually* and unassisted written all they can observe, and made their drawings, have them compare notes by reading items in turn, that those who have omitted points may add them and the mistakes be corrected.

4. When the seeds are all up, dig a well-developed **seedling** of corn and one of bean for each pupil to study.

Make sketches under B and C, write the points in which they are alike under "resemblances," and those in which they differ under "differences." When this is done, give them one after another the **other six seedlings** to decide which of the two previous plants it most nearly resembles, and record the name on the proper side of the page. Press the specimens.

A little difficulty will here occur, which I have purposely introduced. The pea seed remains *in* the ground (like the corn), and the onion "backs out" doubled over (as the bean). Explain here that no rule is without exceptions, and that in grouping we must go by the *general* and *greatest number* of characteristics. Hence as the onion is cornlike in everything else, it is allied to it, and the pea is allied to the bean.

5. **Leaves.**—From the garden and cornfield get small sprigs (stem and leaf) of corn and bean plants. Let the class sketch and write notes (see E).

6. When the ideas of parallel-veined and net-veined leaves are learned give a number of **mixed** sprigs of **leaves** (see Step X) illustrating the variations suggested in E.

Let these be **sorted** into piles of parallel-veined and net-veined leaves, and from these add to and verify the resemblances and differences before written. Press and mount cards of leaves to illustrate what has been written.

When the seedlings in the boxes have grown, observe their leaves in the same way.

7. **Flowers.**—Choose the most available flower having its parts in threes (canna or gladiolus), and also one with parts in fives (pea, pink, or morning-glory). Let the class write the resemblances, sketch so as to show the number of parts, and write the differences. Then give several other flowers to examine and range under threes or fives (see F).

8. **Seed.**—Soak some of the kinds of seeds planted for a day. Give a large grain of corn and a bean to exam-

ine, sketch, and write about. Then examine the others and decide which they are most like (see G). Here, again, the *albuminous* seed of the morning-glory will teach caution in generalizing.

9. **Bring an entire corn plant** and also a bean plant before the class. In what respects are they *alike*? Record under "resemblances." Under "differences," as before, note all the points unlike. This will review the other work, and the class can now generalize and group.

10. (H.) Now place "Corn" at the head of one page and "Bean" at the head of the other, and by memory and notes decide under which the plants raised or studied belong.

11. **Question** as follows to fix the associations:

A plant has *two* seed leaves (cotyledons). What is *probable* as to its root? (tap). Stem? (bark, wood in rings, pith distinct, branched). Leaves? (net-veined and varying as to parts, etc.). Flowers? (in fives). Seed? (without albumen).

A plant has a *multiple* root. What is probable as to its cotyledons? (one). Mode of germination? (*pushes* up). Stem? (no bark, threads of wood in abundant pith, and unbranched). Leaves? (alternate, sessile, simple, parallel-veined, and entire). Flowers? (in threes). Seed? (albumen around the germ).

Thus proceed through all the points noticed.

12. Have the class bring parts of plants, and the teacher distribute for the different pupils to decide where they should be grouped, as exogens or endogens.

Whenever the class is keenly alive to such grouping, and can be relied upon to locate a plant properly by its general characters, drop the work and take the next step.

The next step in plant work is Plant Families, Step XLV.

STEP XLII.—THE EARLY HISTORY OF THE EARTH.

Object.—To review and expand the work of Step XXXV, and in attempting to picture some of the stages in the life history of our own earth, prepare for the following steps ; above all, to exercise the powers of concentrated and imaginative thought. The ability to use the imagination in foreseeing each step in any problem is of the highest value, and its cultivation the *main* object of this study.

Time.—Will be about twenty-five lessons of thirty minutes each during the winter term.

Material and Supplies.—The star lanterns, charts of the heavens, telescope, etc., as indicated in the last steps of star work. Ample notebooks for the full notes this non-experimental subject will require. These should be frequently examined with care, that proper habits may be formed.

Preparation of the Teacher.—Must be wide and thorough for the peculiar demands of the work indicated.

Get the connection with the preceding step, and also Step XLVII. Then see the relation of these to those on rocks (Steps XLIV and XLVIII). Read *Ecce Cœlum* (Burr). Master the theory of Laplace as fully as possible. This will be found in its more recent form in Young's *General Astronomy*, Todd's *New Astronomy*, Ball's *Time and Tide*, and *A Glimpse through the Corridors of Time*, *Appletons' Popular Science Monthly*, vol. xx, or *Nature*, vol. xxv.

THE LESSONS.

Owing to the peculiar nature of the end in view, success will depend upon the knowledge and skill of each teacher, and individuality must have full play. Hence it is deemed best to simply indicate the topics and order of their presentation which have proved successful.

The following points should be put to the class in the form of *questions*, and discussed till an answer is agreed upon :

1. Give an **oral quiz** on the outline of Step XXXV. This will refresh the subject and aid any new pupils.

2. **Explain** the meaning of **hypothesis**, and lead the class to see how helpful such tentative forecasts are if constantly held open to revision, and that in the attempt they are about to make of imagining how the earth came to its present condition much may be shown by future discovery to be very incorrect.

3. **The sun**, all his **planets**, and their **moons** were **once a nebula** (Todd, p. 466 ; Young, p. 516).

4. Through cooling, condensation, and rapid revolution **portions** became **separated**, among which was our earth, and from her again separated the moon (Young, pp. 516-518, and Todd, p. 467).

(Illustrate by the bursting of huge grindstones or fly-wheels, etc., Step XXX.)

5. **The less volatile substances** (sand, lime, iron, etc.) would **first condense** to a liquid sphere.

(Illustrate by the "spit" which drops so quickly from the flame of a steel converter (Step XXXV, § 17.)

6. The more easily vaporized water, carbon, sulphur, lead, etc., would remain, covering this liquid sphere with a **dense envelope of gases** and vapors.

7. **These heated vapors** would

(a) **Rise** to higher altitudes (convection).

(b) **Radiate heat** into space and condense to thick clouds (as the smoke of furnaces, steam of locomotives,

or "thunder heads" of summer; Tyndall's Heat, pp. 408, 409).

(c) Also **cool through** the **expansion** due to diminishing pressure at great heights—steam from boiler; fog in bell jar of an exhausting air pump (Tyndall, pp. 45–47); the cold exhaust of a compressed-air motor; air from a bellows through a narrow opening, etc. (Tyndall, pp. 27, 28).

(d) These dense masses of vapor would cause **complete darkness** except for light from the heated sphere within. (Remind of cloudy days, smoke from a city, etc., and imagine what would be the result if *all* the water and carbon were in the air.) Might the sun, moon, and stars be *shining* and still no light come through?

8. The condensed vapors would be continually falling in **acid rain**, to be revaporized and rise again. (Remind of the great capacity of water for heat, and discuss the effects of this on the cooling of the central sphere.) How would the dense envelope of gases and vapors, particularly H_2O , SO_2 , and CO_2 , surrounding the globe affect its cooling? (See Tyndall, pp. 365–368, 404–416, etc.)

9. As heat was lost through radiation and evaporation the fluid globe **began to solidify**.

When might this *first* begin?

Is solid rock lighter, or heavier, than fused? (Ice, cast iron, and other crystalline solids *float* in fusing or solidifying.)

10. **A crust** covered the earth cool enough for water to remain upon it. Day began to be distinguishable from night. Could sun or moon be seen?

11. **A universal sea** of hot water loaded with mineral substances enveloped the globe.

12. Further cooling and the contracting **crust wrinkled into ridges** (land) and **hollows** (seas). Volcanic outbursts frequent and violent. (See Judd, Volcanoes, p. 260.)

13. **Torrential and corrosive rains** fell on the emerging land, sweeping it in mud, etc., back into the sea.

14. **Tremendous tides** swept the shores, aiding in erosion, and transported the detritus into deep water (Time and Tide, pp. 144-154).

15. **Vast beds of sediment** accumulated off the coasts.

16. Under these vast blankets of sediment the **internal heat** softened and **weakened** the ocean bed. (Diagram on the blackboard. See Le Conte's Geology, pp. 252-260.)

17. **Heat** from below also **penetrated the beds of sediment**, causing semifusion, crystallization, and consequent expansion. (Water to snowflakes; ice expands; castings of iron and type metal are "sharp"; Step XX, §§ 7, 8.)

18. The **enormous lateral pressure** of the shrinking arch of the earth's crust mashed this softened mass into slowly rising additions to the land area.

19. While this (11 to 18) was going on, the **acids and minerals** dissolved in the ocean waters were **uniting** to form solids, which settled, and the waters became purer.

20. As the ocean and land cooled, more and more of the vapors surrounding the forming earth condensed, and the **atmosphere cleared**. **Day and night** became more marked, and at last the sun and moon could be seen.

21. The land was continually being worn away by the rain, and **soil** was gathering **in the valleys**.

22. When the ocean was pure enough, **life began**, and as the atmosphere cleared it was transferred to land.

23. Atmosphere, ocean, and life now worked together to prepare for **man**.

Review by (1) each pupil telling what has particularly interested him; (2) class ask questions on points needing more explanation; (3) teacher completes what may have been omitted by questions.

Meet evenings for star work. The pupils will now be old enough to enjoy and profit by the use of such star lanterns, maps, telescopes, etc., as they can gather.

Ways which have proved successful in the past may be suggestive to others.

A Star Party.—Provide blank calling cards or pieces of heavy drawing paper, enough for all who are invited for some moonless night. Lay tracing paper over a star map or the side of a star lantern, and mark the distinguishing stars of *half* as many constellations as you have cards, and indicate “up” by an arrow tip. Adapt your choice to the age and character of your guests, as well as to the time of the year. Lay these tracings on the cards, and prick through each star into the card, doing a pair of each. Now gum gilt paper, or use gilt paint, to mark the stars, using dots for the smallest, and 3, 4, 6, and 8 points from a dot for the succeeding sizes up to the first magnitude. Now find appropriate quotations (see Bailey’s Astral Lantern or Primary Astronomy; Chambers’s Story of the Stars; Serviss; the Bible; and Gore’s Scenery of the Heavens) and place half on each of the pairs of cards, indicating the break in the quotation by dots (. . .) on each card.

For children, indicate *up* by an arrow point, but omit this for more experienced youths. In case these “parties” are repeated, or it is intended to make use of telescopes, add nebulæ, double stars, etc., to the cards.

As the guests arrive give each a card, and say that the mate is to be found in some one else’s hand, and that both together are to find the constellation. If it is desired to make the matter competitive, let each couple return their cards as quickly as the constellation can be named, and get others, keeping a record of how many each names.

Celebrate astronomical events, eclipses, occultations, etc.

For a “Mars opposition social” a two-foot paper globe (sun) was made from hoops, and across the fields or in house windows lanterns of appropriate colors were placed to represent the planets at distances of one foot for each

400,000 miles, the sun, earth, and Mars in line. In the house a fourteen-foot strip of board carried the pins and balls of Step XXIV at two mm. to each 1,000,000 miles.

Photographs of Mars, astronomical literature, maps, etc., were laid on tables, and after a short address on the occasion, music ("Beautiful Star in Heaven so Bright," "Stars of the Summer Night," etc.) was provided.

Star clubs might be made very popular. Vary the requirements to suit those it is desired to interest, have suitable papers at times, and stimulate attendance by "honorable mention" or prizes for those having the most constellations or single stars learned, double stars resolved, nebulae located, etc.

Next Step XLVII—Other Systems than Ours.

STEP XLIII.—COINS AND COINAGE.

Object.—To keep up the thread of work begun in Man at Home, and increase the knowledge of these interesting records of the progress of the human race. The relation of this work to history and geography may also prove very helpful, and the two should go hand in hand.

Time required will depend on the enthusiasm of the instructor, but should not exceed twenty lessons of science time.

Material.—Gather all the coins which can be procured, including a full set of our United States money (bills included).

The lessons, as to method and procedure, must so depend on the instructor and his available material that only general suggestions can be made.

Base the work on a study of how coins have been evolved by the necessities of the race from their primitive form to the beautiful work of art seen to-day.

“The Evolution of a Coin” might well be the motto.

1. **Study** the **oldest** procurable **coin**, and in history and geography seek the reasons for its metal, device, etc.

2. **Take** the **next oldest** in the same way, bringing out the origin of each change in metal or alloy, shape, weight, device, etc. Continue this by the best available series of types to show how necessity has led to one and another of the variations.

3. **Study** the processes of our own **mints**, their location, and why there.

4. By appropriate exercises learn the nature and value of **our own coins**, and the meaning of their mint marks and dates, mottoes, and devices.

5. Consider why **paper money** is used ; its denomination and manufacture.

6. **Laws regarding** the crime of **counterfeiting**, and what it consists in.

Notes should be kept by the pupils of all this work, illustrated by **rubbings** of both obverse and reverse of each coin particularly studied. This will be facilitated by cutting a hole for the coin in thick cardboard, so that it will not slip while the impression is being made. This will necessitate *heavy* paper for the notebooks, or interleaving with drawing or thin and *tough* linen paper for the impressions.

The competent teacher will find abundance of inspiration in this subject, and it will open a new vista to the pupil.

Next Step XLIV—Rock Making.

STEP XLIV.—ROCK MAKING BY PHYSICAL AGENCIES.

Object.—So far, the steps of both the mineral and astronomy lines have been converging on this interesting subject, which is to introduce pupils to the more thoughtful consideration of the preparation of the earth for the coming of life.

The study of pebbles, sharp stones, molecules, and minerals has been in the direct line of preparation for the study of *rocks*, of which this step is the beginning.

The lessons in astronomy have led up to the grand theory of Laplace, and opened the way to answer the question asked at the close of the molecule study—"What is *another* way, besides the action of frost and roots, by which hard rocks have been reduced to fragments?"

The lessons in plant and animal life have made the pupil somewhat familiar with the life of *to-day*, and so to hold the key which will unlock the *past*, and help understand something of fossils, coal, and lime rocks.

As, aside from humanity, there is no *grand*er study than astronomy, so there is no more *comprehensive* study than geology (and its included chapter, physical geography). Happy the pupils who, after due preparation, can have wise instruction in this all-reviewing, all-embracing, and all-harmonizing subject!

Time needed.—Will vary with the preparation of the teacher and class; but an average will be about forty lessons of thirty minutes each.

Material.—In sorting, the child simply handled and saw; later, in Metals and Minerals, the material was *selected* for test and experiment; now a step in advance is to be taken, and, specimen in hand to observe, the pupil is to exercise his *reasoning powers* in seeking the lessons each can teach. This will often require larger and heavier specimens than in minerals. The following list has been carefully revised, and while, at the suggestion of Prof. O. W. Crosby, some changes have been made, it is essentially the same which has proved satisfactory in eight years' use.

These specimens are chosen in harmony with the following brief

Outline of Plan.—1. Review the class on the theory of Laplace (see Steps XXXV and XLII).

2. Study volcanic and dike rocks.

3. New ways of making sharp stones (No. 2 reduced to fragments).

4. Sediments sorted and deposited.

5. Solutions deposited; chemically formed rocks.

6. Fragmental rocks.

(The *numbered* specimens are for the *pupil*; the others for the teacher's illustration, although the more the pupil has the better.)

1. Pumice.

2. Cellular lava.

3. Basalt (compact).

Basalt (columnar).

4. Trachyte.

5. Obsidian.

6. Felsite (porphyritic).

7. Diorite (coarsely crystalline).

8. Granite (coarsely crystalline).

Furnace slags (glassy, cellular, etc.), iron ore, limestone, and coal.

Rock with cracks.

Stone split by frost.

Stone split by roots.

Rock with lichens on it.

Rock scaling off on surface.

9. Rock containing pyrite.

Cubes of clay.

10. Rusted pyrite.

11. Pyrite in coal.

Bottle of effloresced iron sulphate.

Bottle of air-slacked lime.

Brick burst in burning from inclosure of limestone.

Red clay.

Gray clay.

Glaciated bed rock.

Glacier "tool" (pebble) showing striæ.

12. Gravel.

13. Sand.

14. Clay.

15. "Scale" from teakettle or boiler.

Stalactite.

Stalagmite.

Mexican "onyx."

16. Oölite.

17. Limestone.

18. Dolomite.

19. Bog iron.

20. Siderite.

21. Gypsum (massive).

22. Rock salt.

23. Plaster (from wall of house).

24. Conglomerate.

25. Breccia.

26. Red sandstone.

27. Gray sandstone.

28. Shale.

Boxes to distribute.—These may be the cardboard ones used for minerals, but stronger ones of wood can be easily made by the pupils, and are much better. (Here is a chance for the *carpenters* of the school.)

Where to get.—Many of these can be gathered, especially the illustrative specimens, but the suggestions under Steps VIII, XIV, and XXXVII will apply here.

The cost will be about the same as for an equal number of minerals. Have them come by *freight*.

Store Boxes.—Large 100-cigar boxes will hold thirty specimens of most of the rocks; where one of these will not do, take a starch box or two cigar boxes. For labeling and arranging, see Minerals (Step XXXVII). All rocks should have *numbers* on them to correspond with the list (see Step XIV for directions about this).

Notebooks.—Uniform and large enough for this step and the next (XLVIII).

Literature.—Crosby's *How to Study Minerals and Rocks* (75 cents) will be especially helpful; also Winchell's *Geological Excursions* (\$1); Shaler's *First Lessons in Geology* (\$1). For illustrations and reference I like Dana's *Manual of Geology*, last edition (\$5), Le Conte's *Geology* (\$3), and Judd on *Volcanoes* (\$1.50). No book was ever more interesting to me (as a boy) than Tenney's *Geology* (\$1). He was a noble man, and although the book is out of date, the *spirit* of it is delightful. Have several copies for the class to read, or give as prizes.

Preparation of the Teacher.—While wide and profound knowledge will find ample scope in such work, let no one hesitate because of lack in that direction. Do not *cram* in any case. Handle over the material and study it in connection with what you find in books. Especially *think* over the matters which may not be clear, try to imagine just how things were done or made, and the subject will grow in clearness and interest to you, just as I trust it will to your pupils. If need require, be a *learner*

with your pupils. No one who has not tried it knows the delightful lessons a teacher and class can have studying together. Make personal visits to all cuts, quarries, gravel pits, ravines, stone yards, mines, etc., there may be near you, so as to gain in observation and be ready to lead field excursions.

Winchell's book will be suggestive in such "walks," and if other teachers or some geological friend can be found to keep you company, so much the better. Bright pupils will aid much in telling where such things are, and be proud to show the way.

THE LESSONS.

These will consist in the examination and discussion of a series of specimens, the whole to constitute a brief Story of the Rocks. Experiments will aid in understanding, and field work make the needed connection with *Nature*. The child will have a fund of observed facts and the experience of former work to build upon. The study of the specimens will quicken his insight and suggest questions for experiment and further observation in the field, these in turn to further aid in his comprehension of this story.

I shall make no attempt at division into daily lessons, but only indicate the steps in the work. *Steady progress* should be kept up all the time. Let *full, neat, and well-illustrated* notes be kept by each pupil in uniform notebooks.

VOLCANIC AND DIKE ROCKS.

1. The first thing is to give the class a brief **review** of the nebular theory of the earth, leading up to a conception of its former heated condition, and that the first rocks cooled from a melted state. Why few or none of these original ("Plutonic") rocks are known will appear later. (Class keep full notes.)

2. Give the class **specimens** of the first eight rocks, and let them write a label to go under each, numbering the labels to correspond with the rocks.

Place diagram No. 1 on the board, and explain the use of different ways of marking (by dots, dashes, broken

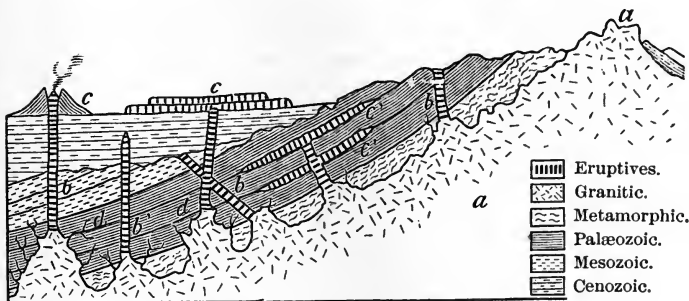


FIG. 7.—Section of earth's crust. (Le Conte.)

and curved lines, colors, etc.) the different strata on such charts.

3. Talk with the class about **glass making**, how sand is hard to melt *alone*, but that the addition of some alkali (soda, potash, or lime) or of some metal (iron or lead) makes the sand melt more easily.

Show fragment of green or blackish bottle glass, that the class may see how iron *colors* the glass.

How will iron affect the specific gravity of the glass? (Heavier.)

Let some pupils (after school) compare the specific gravity of a lens or imitation gem with some Bohemian or hard glass, and make a written report. Which has lead in it? Let others test the fusibility (on a coal fire or with blowpipe) of various kinds of glass (black bottle, greenish, window, lamp chimney, etc.), and also report in writing.

4. The **slag** from iron furnaces is also a glass, which results from the fusion of the earthy impurities of the ore with the limestone put in for that purpose.

The class *should* visit a blast furnace and bring home samples of the whole process for the school and private collections. If this can not be, by the aid of pictures and samples go through the steps very carefully with the class, as it will greatly aid in true concepts of Nature's work.

Why is the slag so heavy? (Iron.)

So dark colored? (Iron.)

Why is some solid, some cellular, and some glassy? (Cooled *slowly*; puffed up by the imprisoned gases, or cooled very *quickly*.)

To show how glass and slag resemble minerals, let us examine the table on the next page.

Sand (SiO_2) behaves like an acid in many ways, and so is called an "acidic" mineral. On the other hand, the oxides (rusts) of potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), aluminium (Al), or ferrum (Fe), etc., are called *basic* substances.

From the table tell me the most highly "acidic" substance. (Sand.)

What is its color? (Light.)

Its fusibility? (Very difficult.)

What is the most "basic" glass? (Flint, or slag.)

How about the color, specific gravity, and melting of slag?

Are light, or dark, colors indicative of silica? (Light.)

How does *lime* (CaO) seem to affect fusibility? (Aids.)

Are *heavy* minerals most apt to be basic, or acidic?

5. By the aid of pictures and written descriptions try to give the class some idea of **volcanic phenomena**, referring to the section of the earth and the specimens to illustrate. (In referring to the specimens always do so by



COMPOSED OF	SiO ₂ .	ALKALINE EARTHS.			ALKALIES.		Metallic oxides.	Color.	Sp. Gr.	Fusibility.
		CaO.	MgO.	Al ₂ O ₃ .	K ₂ O.	Na ₂ O.				
Sand (per cent).....	100	..	..	..	..	..	..	2.60	Infusible (7)
Bohemian glass.....	73	10	..	..	17	..	..	2.50	Hard.
Flint or "paste" glass.	52	..	..	..	14	..	Lead (33)	3.32	Very easy.
Slag.....	Sand,	limest	one, and	clay.	..	..	Iron ore.	Heavy.	Easy.
Orthoclase.....	65	..	..	18	17	..	..	2.55	Hard (5).
White mica.....	48	..	..	39	9	..	Iron (4).	2.80	Hard (6).
Black mica.....	39	;	19	18	10	..	14	2.90	Difficult (5).	
Labradorite.....	53	13	..	30	..	4	..	2.70	Easy (3).	
Hornblende.....	51	13	18	10	..	..	8	3.15	Easy (3).
Augite.....	50	22	13	7	..	..	8	3.35	Easy (3).

name, and let some pupil verify by *numbers*.) For such descriptions see Johonnot's Geographical Reader, The Last Days of Pompeii, and magazine articles on eruptions in Java, etc.

The matter thrown or poured out of a volcano in a melted state cools under varying conditions to give us these eight rocks, which are samples of *many* kinds.

Let the class tell what they can about these rocks, comparing them with the artificial lavas of the glass works and iron furnace.

6. **Question**—after the pupils have told what they can—as follows:

Which rocks cooled quickest? (Pumice and obsidian.) Why?

Which slowest? (Granite and diorite.) Why? (Large crystals.)

Which quickly, but under pressure? (Obsidian.) Why? (Compact.)

Which quickly at the surface? (Pumice.) Why? (Cellular.)

Judging by weight and color, which is the most *acidic* rock? (Pumice.)

Others? (Trachyte and felsite.) Which the most *basic*? (Basalt.)

Judging by the minerals, the most basic? (Diorite.) Why? (Dark, heavy, and of basic minerals.) Name any you can distinguish.

How about granite? (Acidic, as it has much quartz and white mica and orthoclase.)

Which would melt the easiest? (Basalt and diorite.)

Should the melted basalt flow over the country in lava floods, where would the cooling *begin*? (Next air and cool earth.)

If it flowed between walls of cold rock? (On each side.)

Does rock expand, or contract, in cooling? (Contract.)

Here is a curious result of this contraction. (Show pictures and specimens of columnar basalt.)

Who can tell me which way these columns always run? (From one cooling surface to the other.)

The specimen of felsite was formed where? (Under pressure in some thin sheet (dike) where it was not very long in cooling.)

Which formed first, the scattered crystals or the compact paste? (Crystals.)

Any rock spotted with scattered crystals is called a *porphyry*.

Arrange a series of specimens in the order of cooling. (Pumice, obsidian, trachyte, and granite; or cellular lava, basalt, and diorite.)

Are any of these in layers (strata)? (No.)

Who can tell me what must happen before we can see a dike? (Erosion, as they are at first covered up by other material.)

7. Let the class now draw and color diagram 1.

This ends the study of volcanic and dike rocks.

NEW WAYS OF MAKING SHARP STONES.

Now proceed to consider how these rocks are reduced to the gravel, sands, and soils of the earth, that the pupil may begin to understand how the original rocky crust was worked over to make stratified rocks, soil, etc.

8. Show a rock **cracked by frost** or roots, and briefly review Step XX.

9. Show a specimen with **lichens** growing on it, and talk of how these grow on the hardest and smoothest rocks. It is supposed these were the *first* plants able to

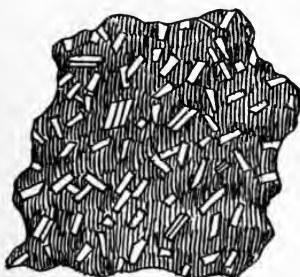
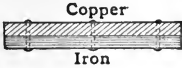


FIG. 8.—Fragment of porphyry (native).

grow upon the bare rocks of the first formed land. That they could corrode the rock and feed upon it is shown by the fact that plates of polished marble and other rocks are acted upon by roots. (See *How Crops Feed*, by Johnson, p. 326, and *Physiological Botany*, by Goodale, p. 246, for an account of these experiments.) Let different members of the class make some polished surfaces of marble, basalt, limestone, etc., and try it.

10. **Unequal Expansion and Contraction.**—Show the class a “compound bar” (one made of two metals riveted together).  Heat it strongly in a

flame and observe the bending, thus:



Why is it curved? (One metal expands *more* than the other.)

Which most? (Copper.)

Other illustrations are the balance wheels of chronometers and “gridiron” pendulums of fine clocks.

Suppose we had cubical bricks of stone and copper or iron, and should with them build a large and exact cube, using alternate bricks of stone and metal, thus: Now let us imagine this put into a hot oven for a time. What will happen? (Will expand as it grows hot.)

Now it has been found that *stone* expands much less than *metal*; so, as the heating goes on, how about the expansion of the different kinds of bricks? (Metal will expand most.)

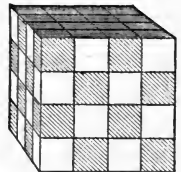


FIG. 9.

Let us now take it out, and when cool what will be the result of this unequal expansion? (**Cracks have been opened** by the expansion of the metal blocks inside pushing out the stone blocks, and on cooling the metal contracted, but could not pull back the stone.)

Metal set or melted into glass or stone frequently becomes loose in this way.

Careful tests have shown that not only do metals and stone differ as to their rates of expansion and contraction, but different kinds of stone do the same.

If we could construct a cube with blocks of pyrite, feldspar, mica, and quartz and heat it, what would be the certain result? (*Cracks* would be made.)

Now, how are rocks usually constructed? (Of mingled crystals of several different minerals. See granite, diorite, and rocks with pyrite.)

If this mingled mass of differently expanding minerals be exposed to the heating and cooling of day and night, summer and winter, what must little by little happen? (*Cracks form.*)

Once the cracks are begun, what will hasten the crumbling of the rocks? (Water will get in and freeze; roots enter and grow, etc.)

Why are glassy rocks and those made of *one* mineral more durable than the other kinds? (Less of this straining from changes of temperature.)

Why are pyrite or grains of magnetite destructive to a rock? (Expand much more than the other minerals, and cause cracks.) Show rock containing pyrite or magnetite and coarse-grained granite and diorite.

Show rocks scaling off on the surface. Can any one suggest a way in which this may have happened? Remind, if need be, of the effects of *sudden* changes of temperature through dashes of rain on a hot day, sudden and cold winds, etc. (see Step XXXI, Exp. 26).

A proof of this is found in the boulders scattered over the northern portions of the continents. When the soil is removed from those covered, and they are exposed to the sun, many soon begin to scale off.

11. **Effects of Wetting.**—Let members of the class weigh fragments of different rocks when dry; soak twen-

ty-four hours in water, and after wiping well weigh again and report results in writing. Place this report on the board for the class to put in their notes. It will quickly be seen that some rocks absorb much and others very little water.

What two results will follow? (Those that absorb water will become **softer** and be more acted upon by **frost**.)

Two cubes of clay will illustrate the first by finding how many bricks can be piled on before crushing occurs in the case of a *dry* cube, and also of a *moist* one. Crayon, brick, shale, and sandstone might be tested in the same way. The action of frost is illustrated by every brick wall, the tile in the mouths of drains, plaster and concrete exposed to the weather, and the poorer kinds of limestone and shale at times used for walls, walks, etc.

12. **Rusting and Effect of Oxygen, etc.**—This wetting is a great aid to the *air* in acting on rocks.

Here is a bottle of iron sulphate. One way of getting this is to pile pyrite in heaps and keep it *wet*. The oxygen of the air acts on the pyrite and changes it to iron sulphate, which, being very soluble in water, is washed out and crystallized for sale. So actively does the oxygen act that it is said such piles frequently take fire.

Pyrite in coal has also been the cause of ships laden with large cargoes of coal *taking fire* from the action of the sea water on the pyrite.

Not only is this iron sulphate very soluble in water, but when exposed to the air it quickly *swells* (show bottle), and also turns to brown iron rust (see rusted pyrite).

Explain the brown stains so frequent on walls and stonework. (Pyrite changed to iron sulphate; the rain washed this out, and as it ran down the stone the air changed it to brown limonite.)

Why has coal frequently a *rusty* look? (Same.)

Why are ships laden with coal bad to insure?

If you were going to build a stone house, what mineral would you wish to avoid? (Pyrite.)

Give your reasons. (It would cause *cracks* by expanding, wash out after change to iron sulphate, and cause rust stains.)

Yes, and there is another way in which it would tend to tear your house down.

I once left a small candy jar full of the green crystals of iron sulphate for a whole year with only a loose cover on. When I examined it the green crystals had crumbled to such a bulk of brownish-white powder that the cover was lifted clear off, and much lay in a pile about the jar.

Another example is this bottle of air-slacked lime.

Who can tell how lime is made? (Limestone is heated (burned) till the CO_2 is driven off.)

What happens when this is done is shown by this deformed brick. A piece of limestone was in the clay, which, when the brick was burned, became lime, and *swelled* so as to burst the brick.

Have any of you observed other examples of lime swelling? (When the mason puts water on it to make mortar it grows hot, swells, and crumbles to powder.)

Yes, and I once saw some barrels of it which had been stored too long in a damp warehouse. It had taken water from the air, and not only were the barrels heaping full, but almost every one had *burst its hoops*.

Should water and air cause pyrite to change to other things inside a rock, what would happen? (Tend to pry the crystals apart.)

There are other minerals which would behave in much the same way, but pyrite will do for a sample.

13. **Solution.**—We have already seen how some of a rock (pyrite) can be washed out. There are other ways in which water acts. In the study of Rounded Pebbles (Step XV) we followed the vapor of water as it rose from the sea, traveled with the wind over the land, condensed on cool mountain tops or by cool winds to rain, and, falling, made brooks to round the sharp fragments made by

frost, etc., and wear the land into hills and valleys. At that time we spoke of a part which, instead of running *off*, sank *in*. Let us now follow this portion and see what it does in earth making.

The rain in falling through the air dissolves some of the CO_2 and other things it meets there. Soaking into the decaying leaves of the forests and turf of the fields it gathers more CO_2 , and becomes **carbonated water**. Test some such water with lead-acetate solution (milky precipitate).

Let us see how this affects the rocks.

Experiment.—Here is an eight-ounce bottle with a rubber cork which fits it snugly. I will fill it full of water, cover the mouth with this glass slip, and invert it in this pan of water. I use this apparatus to run in CO_2 gas (see Exp. 4, Step XXXI) till one third of the water is displaced. Next I cork it under water, and then shake sixty times. Replacing the mouth below the water, I will loosen the cork, while you watch the surface of the water in the bottle. It rises. Why? (Gas has been partly absorbed by the water.) Shake again and repeat. See, nearly all the CO_2 has been taken up, and we now have a bottle of “carbonated” water. I drop in a bit of blue-litmus paper. (Turns *red*.) This shows the water is slightly——? (Acid.)

Watch closely while I put in this dropper full of strong limewater. (Milky, and then clears again.) Yes, the CO_2 and lime at first made a little cloud of **calcium carbonate**, but the acid water quickly *dissolved* it. Repeat this as long as the water will dissolve the milky cloud, shaking, if need be, to make it do so. If an estimate is now made as to the number of c. c. of limewater that have been added, the solvent power of CO_2 water on lime will be a surprise to all. Test a little of this water for lime by ammonium acetate. What other minerals are much like this calcium carbonate in composition? (Marble, limestone, and dolomite.)

Kentucky, Palestine, and other regions are underlaid by limestone, which has cracks (joints), letting the surface water down among the rocks. (See Geographical Reader, or other description of the wonders of Mammoth Cave, and read to the class or tell them.)

How do you explain such caverns in limestone? (Carbonated water has slowly removed the stone.)

Kentucky has always been famous for its fine cattle and horses. Why is the State so good for stock? (Luxuriant grass.)

Had this dense growth of grass anything to do with the caves? (Rain got much CO_2 from the thick mat of decaying turf.)

We shall meet this dissolved limestone in curious ways after a while (Step XLVIII).

CO_2 water can also dissolve iron from the soil (see Le Conte, pp. 136, 137).

Did you ever see rust stains on white cloth, or notice grass or wood that had been in contact with rusty iron? (The iron seemed to have *rotted* the cloth and wood.)

Yes; it was really *burned*. This would, if continued, change the red rust to *brown* limonite. Here is a bottle of freshly boiled water. The CO_2 has been nearly all driven off by the boiling, and I will put in this brown clay (or gravel) and cork it. John may shake it while I put some of the same clay (or gravel) in this bottle of freshly carbonated water. Samuel may shake this while I show the class a very **delicate test for iron** in solution. Then we will test the water we have been shaking.

1. Water + HCl + KCyS = nothing (the water is free from iron).

2. Add to 1 — a pinch of FeSO_4 = *blood-red* color.

This makes an easy and sure test for *iron*.

Now filter the water from our two bottles and see.

1. Boiled water + red clay + HCl + KCyS = no trace of iron.

2. Carbonated water and red clay + HCl + KCyS = red tinge (iron in solution).

In the short time we shook it only a trace of iron could dissolve, but when such water is slowly soaking through gravel and sand beds all day long year after year such "littles" become like the drops in the ocean or sand grains on the shore—a *great deal*.

Why are some clays and sands gray? (Iron washed out.)

Explain why the clay under peat bogs and masses of rotting leaves in forests is light colored. (CO₂ from above removes iron.)

In what are called "red" clay or gravel lands the soil by a rotten stump and by the edges of gullies where water runs is often *gray*. Why?

Carbonated water can **dissolve** the **alkalies of feldspar**. Examine granitelike boulders and see if there is any evidence that some kinds of mineral are being removed faster than others (rough surface, the quartz grains standing up above the feldspar).

Which is seemingly untouched by the weather? (Quartz.)

As the alkali of the feldspar is removed there remains a *clay* with the sand grains scattered through it.

Will such a clay be red? (No iron.)

If the rotten rock contains hornblende or augite? (Brown clay from the abundant iron.)

Mineral Springs.—As the rain thus washes the alkalies from the feldspars, the iron from the soil, and eats the limestone into caves, it is sinking lower and lower through the crust. Some, indeed, runs off in underground streams (Echo River, in Mammoth Cave), but much of it keeps on sinking till it comes to some solid layer (stratum) of clay or rock it can not get through. It is then obliged to soak along in whichever way the layer

slants till it comes to some bank or crack, where it issues as a *mineral spring*.

What "mineral" this spring will contain depends on what it has found to dissolve in the rocks and soils it has passed through. If through limestone, it will be a "hard" water (curdles soap).

If through red clays and gravels, it will be an "iron" water, and make everything around it brownish, like the pyrite stains on stone.

If through rocks containing feldspar, it will be "soft," with alkali.

If through salt deposits, it will be a "salt" spring.

Have the class draw diagrams showing the origin of springs and artesian wells. Also model in clay or with sheets of oilcloth or rubber for the lower, impervious layers, and sand or fine gravel for the water to pass through.

14. These **cause** what is termed **weathering**:

Splitting by *roots* and *frost*;

Corroding by lichens and plants;

Unequal expanding and contracting;

Softening and **solution** by water;

Changing by the **O** and **CO₂** of the air;

Dissolving by **carbonated** water.

Some rocks we have found very weak because of their mixed crystals; others weather much more slowly (or not at all) if of one mineral or protected by a layer of soil.

How has Nature arranged to keep the surface clean, so that the weathering can go on? (Winds and rain.)

Yes, these keep up a continual dusting and washing, leaving the rock in the best possible condition for more weathering.

15. There is one other very interesting and remarkable way in which sharp stones, pebbles, etc., are made. This is by

Glaciers.—We have more than once noticed how the cool tops of mountains caused the moisture of winds to

fall on them as snow. Now, even under the great heat of the tropics (what are they?) some high mountains keep this snow cap all the time, while at the polar regions much more snow falls each year than the short summer's heat can melt.

What very terrible thing might have been left unprovided for had human wisdom had the planning of this beautiful world? (The snow would have kept piling up higher and higher on the mountains till it fell over on the surrounding country, and at the poles till the oceans were drained *dry* and the earth began to reel under the shifted load, and *death* reigned supreme.)

How this unmelted snow is to get melted and return to the oceans is the interesting subject we will now consider.

When a boy I used often to see where the prairie chickens had been burrowing in the snow banks, or the coveys of quail had been huddled under some snow-laden bush.

What did the birds want in the snow? (To keep warm.)

Suppose I had a fur coat hanging in a cold shed where no fire was; would the coat be warm, or cold, to a thermometer? (Cold as the shed.)

But if I put it on it would make me feel warm. (Would keep the heat of the body from getting out and being lost.)

Why was it that when we used to haul hay or straw and stack it on the frozen surface, the ground would soon become thawed out under the stack? (Kept heat of the earth in, as the coat kept that of the body.)

A heavy fall of snow often comes on the hard-frozen ground. If it lies for some time what takes place under it? (Ground thaws.)

Doubtless you have seen the large, handsome St. Bernard dogs. Why are they so called?

What wonderful things are told of them ?

Now these things happened near or among these very snows we have been talking of, and so dangerous and difficult was it to get *over* the high, snow-clad Alps that men set to work to make the famous hole *through* the hard rock called the Mont Cenis Tunnel. The workmen here were much troubled by the great *heat* in the mountain.

Now, do these hints and illustrations help you to see what will happen to the snow cap on a mountain too high for the sun to melt it off ? (The snow will melt underneath.)

Good ! I am glad you thought of it, for that is just what must happen. It does not, however, melt to water, as you suppose.

When wet snow is squeezed *hard* what does it turn into ? (Ice.)

Yes, and as the piled-up snow must be *very* heavy, what will happen to the lower layers ? (Will be squeezed to ice.)

Now, melting ice is a curious substance. A machine has been made in which *fragments* of ice become a solid ball or cup or cube by simple *pressure*, the pieces freezing together as though water had been poured in the mold and frozen (see Le Conte, p. 59).

If you want to try some experiments, drop some pieces of ice in warm water, and when flat surfaces are brought together you will find they *freeze into one*.

Pass a thin copper wire over a cake of ice supported on two chairs and hang a large stone to the wire. After a while the wire will have passed *clear through* the ice, which, however, is still *one* block. How did it happen ? (Wire conducted the heat *into* the ice and so melted its way through, but the ice refroze as fast as the wire passed.)

Heavily loaded sleds (with iron shoes) often "stick"

when they stand a moment. Why? (The "shoes" became warm through friction, and when the sled stopped a thin layer of water formed under the shoe and froze it to the surface on which it rested.)

Now, to go back to the snow on the mountains: The heat from below softens the snow, the great pressure squeezes it into ice, and also forces it slowly out from under the snow into the valleys on the sides of the mountain, where it becomes the ice rivers we call **glaciers**. These are slowly (two or three feet a day) forced to slide down the valleys, gathering on their backs great loads of stones and earth from the mountain sides through which they pass. (Show pictures.)

What will be the effect on stones which get between a glacier and the sides or bottom of the valley? (Crushed, rubbed, and scratched.)

Here is one of these "glaciated pebbles," as we call them. See how worn and scratched it is. What will be the effect on the valley? (Also scratched and worn.)

Yes; look at this piece of rock cut from such a valley bed. So, grinding and crushing the rocks in or under it, and scratching and polishing the bottom and sides, the glacier moves on till it gets into the warm valleys. Here it——? (Melts.)

Yes, and drops the loads of earth and rock it has brought.

The rubbing of things together always causes——? (Heat.)

Which will do what to the under surface of the glacier? (Melt it.)

This explains, in part, the stream of water we always find issuing from the end of a glacier.

Is it clear, or muddy, water? (Muddy.)

Why? (From the worn rocks.)

Name some such rivers. Could you examine the end of a glacier, what would you see? (Heaps of *mixed*

earth and stones, part of the latter still "sharp"—never having got beneath the ice—and part rounded and scratched. The bed rock and sides of the valley would also be scratched and polished.)

If you should find such mixed material where no glacier was, what would you conclude? (That one *had* been there at some time.)

Look about this place, where wells, cuts, or quarries have cut into the earth, and see if you find any signs of this land we dwell on ever having been connected with glaciers.

So much for the mountains in countries where the valleys are warm. But this will not apply to lands in **polar regions**, where the summers are short.

Name such a country. (Greenland, Iceland, Alaska.)

As the snow keeps piling upon the land the glaciers *have* to keep pushing out till at last they come to——? (The sea.)

On they advance into deeper and deeper water, till the end at last floats, and huge pieces break off as——? (Icebergs.)

(See excellent illustration in Le Conte, pp. 43-65.)

Now look at this chart of ocean currents and tell me what is the end of this? (Icebergs are carried by currents into warmer waters, and there melt, dropping their loads of stone and earth in huge submarine "banks.")

The name of both "bank" and of a very useful fish which feeds on something which likes to live in the mud and stones found there, I saw marked on a box in the grocery. See if you can find what it is? (Geo. Codfish.)

Find Georges and Grand banks on the map, and the next time you have *fish balls* tell the family how the "banks" came.

How have we got our piled-up snows back to the ocean? What have we found was another way of making sand, gravel, etc.?

THIS MIXED MATERIAL SORTED.

16. As the rocks are cracked by roots and frost and the heat of the sun, eaten away by roots and CO_2 water, and rubbed, ground up, and crushed by glaciers and moving water, the sand, clay, and pebbles made are also **sorted** into beds.

What is it that can do this? (**Moving water.**)

Yes. Let us think of a brook or river. We know that the *deeper* it gets the harder it must press on and against anything on the bottom. We also know that the *swifter* a thing moves the more work it can do.

When are brooks and rivers the swiftest and deepest with us? (In the spring.)

That is also the time when the ground is soft, and loose from its winter's freezing, and as the water rushes along it tears away its banks and gathers up much of the loose material made by weathering. The turbid mass of muddy water rushes on, carrying the sand and mud, and pushing or rolling the gravel and stones.

Presently it comes to a lake or ocean. As it runs against this body of stiller water the current of the river has a *check*.

How will its carrying power be affected? (Lessened.)

Which part of its load will be first dropped? (Pebbles and stones.)

Then a little farther on will drop the—? (Sand.)

While from the quiet waters of which it has finally become a part will slowly settle the—? (Mud.)

Confirm this by out-of-door observations.

Let us represent the sorting in this long box.

At this upper end we will put—? (Coarse gravel.)

Next? (Fine gravel.)

Then? (Coarse sand.)

Followed by—? (Fine sand.)

Last of all? (Mud.)

As the snows melt and disappear, and the spring rains are past, how will the speed and quantity of water in the brook vary? (Become *less*.)

Where now will the pebbles be left? (Higher up.)

Beginning a second layer in our long box, what shall we put on first? (Fine gravel.)

Next? (Coarse sand, etc.)

What do we notice in this new arrangement? (*Coarser* overlaid by *finer* material.)

As the river becomes still lower, what will be the order? (*No* gravel; only sand and mud.)

Yes; and perhaps in the very driest months the river will be clear of even that, and nothing be added.

Next winter's high water will repeat this, and so the lake slowly but surely——? (Fills up.)

Which end will fill first? (Where the river *enters*.)

How high? (Only as high as the spring freshets can raise the material.)

Is the mouth of the river blocked up? (No, it fills on either side, but keeps one or more mouths open.)

Look on your maps and find the mouths of rivers entering lakes or oceans, and see what these fillings and extensions are called. (**Deltas**.)

How are deltas made? Why have these often several mouths of the river running through them? What kind of land are they apt to be? (Swampy.)

Will it be fertile, or barren, land? (Very fertile.)

Oceans.—The sorting is also done along all beaches, but in a different way.

How does the water move? (Up and back in waves.)

(Have pictures of waves, etc., before the class.)

As the wave advances toward the shore the bottom strikes the shelving beach first and is checked, while the top, continuing on breaks on the shore. A great agitation is caused by this among the sand and gravel of the beach, which we will try to think more about. First, the

bottom is plowed up and violently carried forward by the advancing foot of the wave. Next, the more rapidly moving crest makes a headlong *plunge* among the stones and gravel, driving them against each other, up the beach and against any cliff there may be. While this is taking place the foot of the wave will have begun to run back (as undertow), and will be followed by the retreating water of the crest. What severe rubbing and knocking together this means for the stones and sand of the beach we have before considered, and will be especially realized by those who have been tumbled about in heavy surf while bathing. The sorting will also be readily understood, for the retreat of the wave carries the pebbles with a rattling noise down the beach, to drop them as its force becomes lost, while the fine mud may remain suspended for some little distance from the shore, there to be caught in the currents of the ocean and carried many miles before settling. The tides also help, but we must not speak of them here (see Step XLII, § 14).

SOLUTIONS DEPOSITED—CHEMICALLY FORMED ROCKS.

17. Now that the fragments—gravel, sand, and clay—have been laid to rest on the bottoms of lakes and oceans, let us consider those portions of the rocks which were *dissolved*.

What substances were these? (§ 13, lime, iron, alkali, and salt.)

Lime Deposits.—1. Look in the teakettle at home and bring some of the “scale” you will probably find.

Where has it come from? (The water.)

Yes. What enables the water to dissolve limestone? (CO_2 .)

Now CO_2 can not stay in the boiling water of a kettle, and when it escapes the lime is no longer soluble, and settles on the sides.

Here are some of the curious iciclelike **stalactites** you

will remember as hanging from the roof of Mammoth and other caves.

How did they form? (CO_2 water dissolved the limestone above, and as it trickled down and dripped from the roof some of the lime was deposited and finally grew into these.)

But all the lime is not deposited by the water before it drips from the stalactite. See this **stalagmite**, as it is called. This is formed below, where the water drips or flows off in thin sheets.

How do you account for the columns of such material in caves? (Stalactite and stalagmite have grown till they met and united.)

An interesting example of the rapid growth of such deposits was found in the beer cellars of a brewery burned during the Chicago fire, in 1871. Eight years afterward stalactites twenty inches long and stalagmite lumps one inch thick and four inches in diameter had formed from the lime in the stone of which the brewery was built, aided by a forest of rank weeds which had sprung up on the rubbish. In the beautiful "Mexican onyx" is seen the results of some iron being in the water, causing bands of brown or black.

The story is told of a coal mine in which a deposit of white stalagmite was forming. During the week the coal dust settled on the white stone and made it black, but when Sunday was observed a pure white layer recorded the fact in stone. Sometimes the leaves and moss about such a spring are "petrified" into a stony model of the substance.

At times this limy water soaks among shells, pebbles, or sand.

What will it do to them? (Cement together.)

Show coquina from St. Augustine, and test plaster and conglomerates for the nature of the cement by powdering some of the cementing material and shaking

with weak HCl acid, then to the clear solution apply the lime and iron tests. (See Solution 13.) Effervescence will occur if it is a lime cement. Having deposited some of its limy matter as stalactites, stalagmites, and cementing material, the water passes on to the oceans. In the early history of the earth there must have been a great deal of lime in the sea water and much CO_2 in the air. What would happen from its waves mixing with the air heavily laden with CO_2 can be seen by filling an eight-ounce bottle with limewater and running in CO_2 gas till half of the water has been displaced. Cork well, and shake. A white precipitate of calcium carbonate will form and settle to the bottom. Let the class expose saucers of limewater for a night, and a brittle skin of the same mineral will form on the surface from the CO_2 in the air uniting with the lime of the water. The same thing is well seen where masons have left water standing in a mortar bed.

In the ocean this white precipitate would slowly settle to the bottom as it formed, and the white mud would become **limestone** in time. Should another substance called magnesium carbonate form at the same time and settle with the calcium carbonate, another kind of rock would form called **dolomite**.

If this white mud should form in shallow water the gentle moving by the waves often rolls it into little egg-like grains, which, cemented by the same substance, forms—? (**Oölite**.)

More recently—since life came on the earth—the lime has been removed from seas and lakes in a remarkable way, which we shall consider under Animals.

Iron Deposits.—When iron is dissolved by carbonated water it takes the form of **siderite** (carbonate of iron); and if this water ran into peat bogs, or any place where there was much decaying vegetable matter, it would deposit as siderite or mix with the clay, becoming **clay**

ironstone when in quantity. Should this solution of iron carbonate come to the *open air*, the CO_2 would escape, and stalactites and stalagmites of brown **limonite** might form, as happened with the lime; also leaves, etc., about such water would be coated with the brown rust, and layers of pebbles be cemented, as in the specimen of bog iron. In this way the grains of **iron** scattered through the sands, clays, and gravel from the weathered rocks would little by little be **gathered into the immense beds of iron ore** we find to-day.

What must the water hold in order to dissolve the iron? (CO_2 .)

Where could the CO_2 come from? (Decay of plants, animals, and the air.)

What would be the original color of the sands and clays containing iron? (Brownish red.)

How would the removal of the iron change this color? (To grays and whites.)

Might some siderite be left in light-colored clay or sandstone? (Yes; it is a light-colored mineral itself.)

Gypsum and Salt.—As the continents rose above the sea, portions of the salt water would be separated, as now seen, in what seas? (Caspian, Dead, and Aral.)

Look on the map and see what arms of the ocean have narrow openings into the larger bodies of water. (Red, Black, Mediterranean, Baltic, etc.)

If the mouths of the Baltic and Red Seas were closed, which of them would gradually fill up, and, overflowing at some point, be washed free from salt and become a fresh-water lake? (Baltic.)

Why? (Because of the slow evaporation where it lies, and because so many large rivers run into it.)

What would happen to the Red Sea? (So little water flows in that it would slowly *dry up*.)

What would happen to the mineral in the water? (Would be left in layers on the bottom.)

To take two examples: salt is very *easily* soluble in water, while gypsum takes a *great deal* of water to dissolve it.

Which will deposit *first* in the drying up of a lake? (The least soluble—gypsum.)

On top will rest layers of——? (Salt.)

Now, in Nature, salt mines are almost always underlain by beds of gypsum. How did the two become so placed?

FRAGMENTAL ROCKS.

18. The beds of gravel, sand, and clay at the bottom of seas, lakes, and rivers are under *heavy pressure*. This is shown by corked **bottles** and apparatus lowered into deep water being **crushed**; and **wood** sunk to great depth becomes so full of water as not to rise again (ships).

Deep-water fish show the pressure they have lived under by swelling up (red snapper), the stomach protruding from the mouth in many cases.

Divers for sponges and coral often have their eardrums burst, and come up bleeding from nose and ears.

Now this pressure, aided by the cementing lime and iron we have spoken of, makes of gravel beds——? (**Conglomerate.**)

If there are *sharp fragments* in place of rounded pebbles——? (**Breccia.**)

Beds of sand become——? (**Sandstone.**)

Brown because of——? (Iron.)

Gray? (Because the iron has been washed out.)

Mud and clay become——? (**Shale.**)

Brownish if it contains——? (Limonite.)

Gray when——? (The iron is gone, or changed to carbonate.)

Black, as in the "slate" found in hard coal——? (When it has carbon in it.)

Such slate, as seen in the ashes after burning, is of what colors? (White or red.) Why?

The leaves of plants, shells, and parts of animals are often beautifully preserved in such shale, and are called **fossils**.

Are these rocks in strata (layers)? (Yes.)

Review had better be delayed till the beginning of Step XLVIII. If the work has been carefully done none is needed now.

Material put away.—See Minerals, Step XXXVII.

Earth Making is really the first half of Rocks (the next step in the mineral series), and the completion of the study of fragmental and chemically formed rocks seemed a good place to stop. As to the interest and profit such lessons are to a class, one trial in the way indicated—with *specimens* to illustrate all that is said or done—will be enough to answer the question beyond dispute. I doubt if for *general mind building* any better material can be found than *rocks*.

Next step, LXVIII—Rocks.

STEP XLV.—FAMILIES OF SPRING PLANTS.

Object.—By comparative study of several members of each, to learn the characteristics of important families of plants. Incidentally to continue the work begun in Step XLI. Accurate observation and concise description are vital factors in this work, and are to be persistently cultivated.

Time.—About twenty-five lessons of thirty minutes each in the spring. Take up the work whenever material can be had, alternating with other work should the supply fail. Specimens should be fresh, although it is well to have mounted material (hereafter described) on hand in case of an emergency.

The flowers of spring are more simple and easily compared than those of autumn, and hence best to begin with. The following list of families and their most available representatives will indicate the general plan, which has proved successful, and serve as a model on which adaptations can be made for other localities.

The order in which these are studied is of little consequence except in the case of families which are much alike. These should be studied consecutively, that the *differences* may be more readily detected. Such are grouped by brackets.

Suggested families for the step, and their **most evident general characteristics:** *

* They are *herbs* with *net-veined* leaves, unless otherwise stated. *Exceptions* are ignored at this stage of the work.

1. **Coniferæ** (pine, spruce, hemlock, larch, arbor vitæ, etc.).—Trees or shrubs with needle-shaped leaves, resinous sap, and naked seeds in cones.

2. **Willows** (willow, poplar, cottonwood, aspen, etc.).—Trees or shrubs with dioecious catkins and cottony seed.

3. **Arums** (calla, Jack-in-the-pulpit, skunk cabbage).—Monœcious flowers on a spadix surrounded by a spathe.

4. **Horsetails**.—Plants with harsh, jointed, leafless stems and terminal spike.

5. **Ranunculaceæ** (buttercups, anemone, hepatica, columbine, etc.).—Parts of the flower all distinct and falling to pieces.

[6. **Liliaceæ** (tulip, hyacinth, onion, lily of the valley, etc.).—Leaves parallel-veined. Perianth and stamens regular and of same number. Style of superior ovary undivided.

[7. **Amaryllidaceæ** (yellow star grass, narcissus, snow-drop).—Same as the lilies (6), except that the ovary is *inferior*.

[8. **Iridaceæ** (iris, crocus, blue star grass, gladiolus).—Smooth, parallel-veined leaves, stamens only three, opening away from inferior ovary.]

9. **Orchids** (lady's slipper, fringed and round-leaved orchis, arethusa, etc.).—Leaves parallel-veined. Very irregular flowers, the one or two stamens cohering to the pistil.

10. **Mustards** (stock, candytuft, cress, horse-radish, etc.).—Pungent taste, the four petals regular, and six stamens of two lengths.

11. **Rose family** (apple, peach, blackberry, Geum).—Alternate, stipulate leaves. The regular corolla, and many stamens on the calyx.

12. **Pink family** (soapwort, chickweed, sweet William, etc.).—Simple, opposite leaves from swollen joints. Seeds on free central column of ovary.

13. **Pea family** (vetch, lupine, bean, wistaria, locust).—Compound leaves, stipules. Ten stamens, the fruit a one-celled pod.

14. **Umbelliferæ** (carrot, parsnip, water hemlock, etc.).—Compound leaves, the bases sheathing the fluted, hollow stem. Flowers in umbels.

Preparation of the Teacher.—This step and XLVI are so related that a study should be made of them together.

There is no better preparation than to **illustrate the families** on cards, which will also be available for class work when fresh specimens can not be had.

The Coniferæ is especially good to begin with, as so many members of the family are available in parks, etc., at any season of the year, are so characteristic, and keep so well. Gather a bit of the spray and the cones of as many evergreens as possible. Take a good work on botany (or Newhall's Trees of North America), and, turning to the family, compare your specimens with the text and with Step XII. Having learned each tree and its characteristics, press small specimens of all the sprays (except the hemlocks, firs, and spruces, which will drop to pieces when dry), a couple of the scales from each kind of cone with the seeds, if they can be found.

Procure a couple of nurseryman's illustrated catalogues and a number of stiff cards 6 × 10 inches. On these paste the cuts of such pines as your catalogue supplies, and beside each picture glue strongly a sprig of its needles and two scales, one with the thickened tip up, and the other reversed to show the two seeds at the base. This card (or cards) will illustrate the true pines (needles in *bundles* of two to five, and scales of cones *thickened* at the tips).

On another card place the hemlock and spruce (drawing a bit of the spray or gumming on a few of the scattered needles) with the *thin-tipped* scales of the *pendant* cones.

On another, those with *erect* cones (fir and larch).

On another, those with scale-leaved sprays, their corresponding cone (or berry) entire (as in arbor vitæ, white cedar, and red cedar).

Compare in this connection the corresponding woods of Step XIII.

By the time this is done some very substantial knowledge of and interest in an important group of plants will have resulted, and is now available for teaching others.

By methodical work in some room where plenty of table space can be had it is no severe task to prepare ten or twenty cards of each sort, and then you are ready for class work, if fresh material can not be had.

These cards will illustrate much of a concise botanical description—e. g., Coniferæ: trees or shrubs; soft wood; resinous sap; awl- or needle-shaped entire leaves; the fruit a cone (or berry), with two or more naked ovules (or seeds) at the base of each scale.

Proceed in like manner to illustrate the other twenty-nine families given in the two steps (XLV, XLVI), or such substitutes as circumstances may direct, except that it will not be best to subdivide a family as above suggested for the Coniferæ.

Gather typical material for this wherever and whenever it can be had, label, press, and put away till all of one or more families is ready, and then make one piece of work of the mounting. *Do not label* the cards in any way.

Such work of preparation may well be the avocation of the year preceding the beginning of instruction, and will place the teacher in a position to do effective teaching with ease and certainty of happy results.

Plant seeds, etc., by the aid of the class, to furnish material for the work of the fall, which will continue this (see Step XLVI).

THE LESSONS.

Do not begin till a survey of the available material promises a regular supply, so that the "line upon line" of practice can be sustained for a number of families. As a model and to unify the work of the class, place the following order of record on the blackboard and direct the class to follow it in their study :

ORDER OF RECORDING OBSERVATIONS ON EACH PLANT.

Life—Annual, biennial, shrub, tree, etc.

Root—Multiple, tap, etc.

Stem—Endogen, exogen, branched, wood, sap, etc.

Leaf—Position : alternate or opposite. Vernation, etc.

Parts : stipules, petiole, blade, venation, simple or compound, etc.

Bracts—Position : foliaceous or floral, etc.

Flower—Kind : perfect, complete, regular, symmetrical, monœcious, etc.

Position : terminal, axillary, raceme, umbel, etc.

Calyx : adhesion or cohesion, character, etc.

Corolla : same.

Stamens : same ; anthers, color of pollen, etc.

Pistils : same ; simple or compound, placenta, superior, etc.

Fruit—Kind, structure, etc.

Seed—Number, albuminous or exalbuminous, etc.

The record must be kept in an orderly and concise manner, using diagrams to save space and add clearness.

The notebooks should be wide (eight inches or so). Having headed a page with the name of a family, divide the space into as many perpendicular columns as there are representatives of the family to be studied. These parallel columns will aid in seeking those resemblances which characterize the family.

1. When these details have been explained, **bring** as **complete specimens** (root, leaf, flower, and fruit) as possible of two or more members of the family. Give a named set to each pupil, who will then proceed to head the columns with the names of the plants and in the order given on the board, to record his observations under the name, using any aids in the way of books, etc., he may be able to get. As this work is *classification*, obvious differences should be omitted from the record, and only likenesses noted. It will be best to make the study comparative, recording the character of the roots of one after another till all roots have been examined, then taking all the stems, etc.

2. When all have completed their notes, have one after another **read** his **record** of some one point to the class for comparison and the correction of mistaken conclusions.

3. Let each one carefully consider his record and **decide on** the **briefest** yet **complete characterization** of *all* the given plants (the family), write it at the bottom of the page, and hand his book to the teacher for inspection as to neatness, conciseness, and accuracy.

Would lay great stress on these three points, as much of the educational value of this work lies in the training along such lines. Slovenly work should be rewritten. **Conciseness** can only be acquired by practice, hence commend any advance discoverable.

Accuracy will be the result of a careful study of the material, recorded through a wide vocabulary of understood terms. These must be acquired if not already possessed, and the teacher's criticism should guide in that direction.

Give **especial heed** to the final **characterization** of the family, and while the pupil as yet knows nothing of the other twenty-nine groups in this and the related step, and hence can not yet say what are the *specific* points by

which to distinguish this from all other families he will study, yet the teacher should see that all such points are among those recorded by each.

Do not mark or even tell the pupil what these specific points are, as that will be his discovery when later on he has widened his outlook by the study of more groups.

4. Return the notebooks and have the class read their characterizations aloud for mutual help and criticism.

5. **Give another group** and proceed as above. If the introduction has been carefully made, each will begin to know just what to do and to do it rapidly and correctly. After a few times the reading aloud (2) for comparison may be omitted, and each pupil work individually.

This **individual and unaided work** must be constantly encouraged.

Do not *forbid*, but rather try in every way to create, a sentiment which will scorn to give or take aid, and a pride in independent effort and results.

A clear statement of the loss from being helped and the unkindness of helping has usually sufficed for the majority of a class. The minority must be individually labored with.

To keep the class reasonably together and yet encourage prompt and accurate work, it will be needful to provide (and give distinct credit for) advance work, to utilize the energies of the bright and industrious.

Post a list of ADVANCE WORK open to pupils who have completed satisfactorily all the groups supplied, and let each choose what he desires to investigate.

The following are some suggestions :

1. Bring in new plants of groups studied.
2. Bring in families of your own discovering.
3. Illustrate the groups studied on cards.
4. Begin an herbarium of one or more families, neatly pressed, mounted, and named by some key.
5. With the microscope investigate the minute struc-

ture of the seed, shape of pollen, distribution of stomata, or other peculiarities of groups studied.

6. Learn the properties, distributions, etc., of some group.

7. Subdivide families into genera.

8. Study the *exceptions* to the characterizations made.

9. Continue and expand some of the "relationships" of Step XXVIII.

As group after group is studied and its characteristic features are sought, constant reference must be made to groups previously studied, that each description remains clearly distinctive. This will often involve the striking out of points which at first appeared characteristic, or the adding of features which before seemed unimportant.

The ability of the pupil to do this without aid will be the measure of his profit from the lessons.

Continue the free criticism of (4) at times by letting volunteers place their characterizations on the board for the class to revise.

Review in various ways:

Class and teacher bring in new specimens of groups studied, for the class to locate.

Teacher characterize a group, and class write the name.

Pupils characterize and teacher name, etc.

The results of this work, done in the independent spirit I have tried to indicate, will amply repay the labor of the teacher, and will compare favorably with the substantial results obtained along any other line of true education.

The next step will continue the work of this on the flowers of autumn—Step XLVI.

STEP XLVI.—FAMILIES OF AUTUMN PLANTS.

Object.—To continue the work of the last step by a study of the more difficult flowers of autumn, and further advance the training outlined in XLI.

Time.—About twenty-five lessons in the autumn, before severe frosts kill the flowers and fruits.

Material should be fresh. See last step for suggestions.

Suggested families for the step and their most evident general characteristics (exceptions ignored) :

1. **Gourd** (melon, squash, pumpkin, wild cucumber).—Fleshy herbs with tendrils, flowers monœcious, ovary inferior.

2. **Solanums** (tomatoes, potatoes, petunia, tobacco, etc.).—Herbs, the regular flowers plaited in bud; five stamens, and rank, watery juice.

3. **Mallows** (abutilon, sida, hibiscus, cotton, etc.).—Regular flowers, the many stamens cohering in a tube.

4. **Bindweeds** (morning-glory, sweet potatoes, etc.).—Twining or trailing herbs, corolla twisted in bud, and seeds albuminous.

5. **Compositæ** (aster, golden-rod, sunflower, dahlia, etc.).—Many, regular flowers in an involucrate head. The inferior ovary one-seeded.

6. **Mints** (salvia, catnip, etc.).—Square stems, opposite, pungent leaves, irregular flowers, ovary forming four nutlets in fruit.

7. **Figworts** (mullein, snapdragon, gerardia, "butter and eggs," etc.).—Resembles 6, but *not pungent*, and fruit a two-celled, many-seeded pod.

8. **Borage** (heliotrope, puccoon, stick-seed, etc.).—Fruit as in 6, but stem *round*, leaves *alternate*; *regular* flowers in scorpioid racemes, etc.

9. **Euphorbias** (any of the spurges).—Milky sap, the monœcious flowers surrounded by an involucre which is often petaloid.

10. **Oak** (chestnut, beech, hazel, hornbeam, etc.).—Trees or shrubs, the leaves simple, and fruit a one-celled nut in a cup or burr.

11. **Hickory** (pecan, pignut, black walnut, butternut, etc.).—Trees, pinnately compound leaves, fruit drupelike and embryo lobed.

12. **Sedges** (any).—Grasslike, but the leaves with *closed* sheaths and solid, triangular stems.

13. **Grasses** (wheat, oats, corn, timothy, bamboo, etc.).—Like 12, but the leaves with *split* sheaths on the round, hollow stem.

14. **Ferns** (any).—Fronds leaflike, unrolling at the tip in growth, spores in dots or lines on the back.

15. **Mosses** (any).—Small, “flowerless” plants, stem and leaves distinct, and spores in a spore case.

16. **Lichens** (any).—Incrusting plants with no distinction of stem and leaf, and no spore case.

Preparation of the teacher as in Step XLV.

The lessons should *begin* as in the last step, but the pupils will need less oversight, and can more quickly be left to original methods. If, as suggested in the last step, seeds and slips were planted last spring to supply material for this work, it will also be feasible to give a greater number of members of a family, and by rendering the work correspondingly complex increase its educative value.

Results.—In the nine years of work outlined, some 330 lessons on plants have been planned, at an expense of 130 hours of the child's time (one seventieth of his school hours). He is now able to pass a thoroughly intelligent

examination in botany, and has also been trained and developed in other and highly desirable ways.

Comparing this with the ordinary half year of work on the subject in the high school, after the innate love of childhood has been lost through unsympathetic surroundings in the *grades*, we find him, under the most favorable circumstances of laboratory teaching, spending over two thirds or more as much time in gathering a hurried and technical knowledge of the subject, vastly inferior in scope and thoroughness, and which in large measure lacks the developing power of this systematic and progressive work.

The interrelations of things have been shown, and further and more formal study of plant life will be pleasurable, and productive of results which without this elementary work would be only attained after long and painful effort to correct the paralysis of neglect and opprobrium. Other work has been relieved and lightened. By a study of every-day surroundings the mental powers have not only been trained and "correspondences" increased, but the possibilities of the commonplace have been demonstrated, and a pure and ennobling avocation opened for choice. If these be true, no other commendation of well-planned elementary science work is needed.

STEP XLVII.—OTHER SYSTEMS THAN OURS.

The object of this step is to continue the mental training of Step XLII by a consideration of stellar distances and magnitudes. Incidentally it will add to and widen the ennobling conceptions of the material universe, of which we form so small a part.

The time should be at opportune dates through the year. Some class work and much out-of-door observing will be needed.

Apparatus has already been indicated in preceding star work.

Preparation of the Teacher.—Much the same as in XLII, which should have left a keen appetite for “more” on the part of teacher and pupils. Ball’s *Story of the Heavens* is a recent and helpful book. While not up to date in figures and conclusions, Burr’s *Ecce Cœlum* has never been superseded as an inspiring book, and chapter V could well be made the basis of this step, reading it in the class and testing and correcting its statements by more recent books.

THE LESSONS.

So much will depend on the individuality and personal inspiration of the teacher that it is with great diffidence that a venture is made to say how these shall be given. Personal experience may, however, prove suggestive.

1. Review XLII by thorough questioning and lead up to,

2. Is this the *only* planetary system ?

3. What is the center and life of this, the solar system ? (The sun.)

4. What holds the unsupported planets in their orbits ? (Attraction of the sun.)

5. Through what distances does gravitation act ? (All.)

6. As a whole, what does our system rest upon ? (Nothing.)

7. What must be its state if unsupported ? (In motion.)

8. Toward what ? (It is the purpose of this step to consider some of the *possibilities* in the case.)

9. What is *parallax* ? (See Todd, p. 234.)

10. How far is the moon from us ? What motion has she ?

11. How far is the sun ? What motion has he ? (Young, pp. 458-460).

12. How far to the nearest star ? (Todd, p. 435, etc.)

How far to the base line ?

How far to the angle opposite ?

(Get the radius of some slight curve in railway or driveway from the engineers and lay off the length of one second of arc. The smallness of this will aid in the conception of the vast distance it is desired the class shall attempt to realize. Add the illustrations of the books, placing this important matter in many lights.)

13. The "light year" unit of measure.

How far does light go in a second ?

From the moon ? From the sun ?

From Alpha Centauri ? Polaris ? Arcturus ? (see Todd, p. 439).

14. If one could see events on the earth at such distances what would he now see at Arcturus ? (The events of one hundred and sixty years ago.)

At Vega in the Harp ? At Altair in the Eagle ?

15. What is beyond these stars whose distance is known ?

16. What is the universe ?

17. What is *man* ?

Books of reference should be fully supplied and much used. Encourage comparative work on special points, finding all that is said by available authorities and summing up the matter in writing. Reports also should be had of any individual work done, from the making of a telescope to the learning of the constellations. This will give dignity to and greatly stimulate the *original* element, which is so much to be desired.

Constellations.—Among those so far omitted I would especially advise finding Orion and the Great Dog in the winter, and the Arrow, Eagle, and Dolphin in the summer.

Portfolios of constellations and maps were suggested in Step VII. These should now be called for and perhaps placed on exhibition, due credit being given for all good work.

Close the work by some public celebration, so arranged that the different grades can participate in entertaining visitors with what they have made and learned, the central idea being not to *show off*, but to use what we have for the pleasure of others.

Results.—For nine years a sympathy and wise exercise has trained the natural curiosity of the child.

In some 190 exercises, occupying between sixty and seventy hours of his school time, has a healthy interest in noble things been cultivated. Some of the results, if the work is patiently and progressively done, will be

Increased ability to think to a conclusion.

Helpful concepts for physics and geography, etc.

Discernment of the interrelation of things.

The scientific method of handling questions.

Improved eyesight.

A knowledge of his own powers and preferences.

Resourcefulness for healthy avocation.

Less affinity for evil through the added affinity for *good*.

A healthy mental appetite for knowledge which will cause him to take up the formal study of astronomy or related subjects with ease and facility.

Can *one one-hundred-and-fortieth* of the school time of a fifteen-year-old child be spent to better advantage ?

STEP XLVIII—ROCK MAKING—(*Continued*).

ORGANIC AGENCIES AND METAMORPHISM.

The object of these final lessons along the line of inorganic nature differs in no respect from those given for Rock Making. The *life* element will be introduced, and we shall show how plants and animals have aided in preparing the earth for man, as well as the changing (metamorphic) effects of heat, etc., on the fragmental rocks before studied.

Time needed will be about fifty lessons of thirty minutes each.

Material.—This has been so selected as to conduct the pupil through the continuation of the geological story by a series of concrete illustrations.

BRIEF OUTLINE.

1. Modern shells, corals, etc.
2. Rocks formed by or containing ancient forms of animal life.
3. Modern allies of fossil plants.
4. Rocks formed of or containing ancient forms of plant life.
5. Metamorphic agencies illustrated.
6. Metamorphic rocks.

As in Rock Making, all specimens given to the pupil should have *numbers* on them, and as some of the former series will be needed in this, the numbers are made consecutive.

29. Shells of oyster and clam (in mated pairs).
30. Univalve shells with and without a canal.
31. Specimen of coral.
32. Limestone with fossil shells.
Limestone with fossil coral.
Slide or illustration of foraminifers.
33. Chalk.
Slide or illustration of magnified chalk.
Nummulitic limestone.
Slide showing sponge spicules.
Slide showing polycistines.
Slide showing diatoms.
Diatomaceous earth.
Slide of diatomaceous earth.
Slide showing section of flint.
34. Flint.
35. Chert.
36. Lichens (mounted).
37. Ferns (mounted).
38. Lycopods (mounted).
39. Equisetums (sterile and fertile plants).
40. Conifers (wood, leaves, and fruit).
41. Sphagnum.
42. Peat.
Mud (black).
43. Black shale.
44. Soft coal showing plant remains.
Fossil calamite.
Fossil of fern.
Fossil of lepidodendron.
Examples of vein structure in rocks.
Siliceous tufa.
45. Melaphyre.
46. Gypsum.
47. Amygdaloid.
Agate.

48. Quartzite.
49. Slate.
50. Mica schist.
51. Hornblende schist.
52. Chlorite schist.
53. Talcose schist.
54. Gneiss.
55. Granite.
56. Hematite.
57. Magnetite.
58. Marble.
59. Serpentine.
60. Anthracite.
Petroleum (crude).
Graphite.

Boxes or trays for each pupil had best be of *wood*, as suggested in Rock Making.

Where and how to get this Material.—Gather all you can, and buy what you *must*. Enough of the numbered specimens should be gathered so that each pupil may have a set. The illustrative material should be chosen so that a whole class can see it from the desk. Illustrative charts on zoölogy or geology will also aid, and will tide the teacher over the “missing links” in her series of specimens, as many things can not be *bought*, nor can they be *found* at short notice, and no one should feel discouraged if *everything* is not on hand for the first class; year by year will add to the material an earnest teacher will gather.

I have suggested several slides for the microscope. These can be exhibited at recesses or after school. Should they not be obtainable, bright pupils could put drawings enlarged from geologies and zoölogies on the board, or, better, on thin cloth (in ink), so as to preserve them. The shells can be easily had in cities, and the plants can be gathered, dried under pressure, and mounted on cards.

Cost.—After deducting those specimens already on hand, as minerals, those which can be gathered and found, only seventeen to twenty sets of thirty specimens will have to be bought, and they will cost about \$15. For the slides and illustrative specimens get *good* ones, if you buy, even though only part can be bought at a time.

Store in boxes continuing the plan suggested for the specimens in Rock Making.

Notebooks should be kept. By choice *continue* the one on Rock Making.

Literature.—A good work on zoölogy and botany, with pictures of fossils, will be useful additions to those books suggested in Step XLIV.

Preparation of the Teacher.—Nothing need be added to what was said under Rock Making. The great thing is to continually keep yourself in the position of one who has *seen* some interesting thing and is *showing* it to others. You will not fail in that case of a sympathetic class.

THE LESSONS.

I shall take it for granted that most of the class have had the lessons on Earth Making, and that many have helped order, unpack, number, and put away the specimens bought; have washed the shells, pressed and mounted the plants, cracked up the rocks gathered; hunted in coal heaps for black shale and coal with plant remains; have dug peat and mud in swamps, and copied cuts of magnified chalk, diatoms, and the exquisite foraminifers and polycistines.

Such exercise is conducive to a warm interest, and your class is now *ready*.

1. **Review** Earth Making to freshen up the matter. I give some of the questions which my notes show as having been used.

Wrap an entire set of specimens of Rock Making in papers, and add such things as glass, bottles of water, air, carbonated water, lime test, iron test, etc., making as complete a set of illustrative specimens as possible. Also gather pictures of volcanoes, icebergs, glaciers, deltas, filling of lakes, divers in armor, etc.

Distribute these among the class just as they happen to come, and let each one open his parcel and have it ready to describe when the time comes in your questioning.

What idea did Laplace have about this earth and the solar system ?

How did the earth originate ?

How the moon ?

Give some idea of the cooling of the earth.

Why flattened at the poles ?

What are volcanoes ? Show pictures.

Describe an eruption.

What rocks have any of you that were thrown or flowed out ?

Show me the dike rocks you have. How recognized ?

What rocks that *may* have been part of the original crust ? Why ?

Hold up *pumice*, and tell me about it. (So on through the first eight rocks of Step XLIV.)

Who has a cracked rock ? How made ?

Show me lichens on a rock. What can you tell me about them ?

Show and tell me facts about a rock *scaling off*.

Explain a "compound bar."

Who has a rock containing pyrite ? Why injurious ?

What are the cubes of clay to show ?

What causes the rusting of pyrite ?

What may the swelled iron sulphate show ?

The misshapen brick ?

The red clay ?

The gray clay ?

Show a picture of a glacier to the class, and describe it.

Show picture of iceberg and describe.

What caused this ice to form ?

What can you tell of its motion ?

Where do the Alpine glaciers end ?

What kind of material is found at the end ?

What are the signs of ancient glaciers ?

Where do the arctic glaciers end ?

What do they carry on them ?

What causes them to melt ? Where ? What is formed ?

How is the gravel, sand, and clay gathered ?

How sorted ?

Describe the filling up of a lake.

How is a delta made ?

Where did the scale in the teakettle come from ?

Tell about Mammoth Cave.

How was it made ?

What are stalactites ?

What are stalagmites ?

Mexican onyx ? What causes the brownish veins ?

Where, and how, was oölite made ?

What does the crust on lime water illustrate the forming of ?

Where was all the iron originally ? (Scattered through rocks, and next in soils, etc.)

How was it brought into the great beds we now find ?

Where is bog iron found ?

Where will siderite form ?

What is one way gypsum seems to have formed ?

Rock salt ?

What may a piece of house plaster illustrate ?

How were conglomerates made ?

How red sandstone ?

How does gray sandstone differ ?

How was shale made ?

Are these fragmental rocks in strata ?

Now replace material where it can be seen and easily got at.

2. **Give limestone and coal.**

Here are other rocks in strata. Are they made of pebbles ? Of sand ? Of clay ? (No.)

Let us study about them.

Lime gathered from the sea.

Give each a clam, oyster, or other similar **shell**.

Notice the structure and parts of each.

Test a bit of broken shell in acid (HCl). (Effervesces = CO_2 .)

Try the lime test. (NH_4HO + ammonium oxalate = white precipitate of *lime*.)

Shells, then, are mostly made of—? (CO_2 and lime.)

Examine bits of **coral** in the same way. Speak of coral islands.

Give lime rock containing fossils, and examine.

What is another way limestone has been made ? (Shells and coral.)

Where did these animals get the lime ? (From their food.)

How did much of the lime get in the ocean ? (CO_2 water of rivers.*)

* Care must be exercised in the use of proper words in this connection, as the greatest confusion (and *error*, I think) exists in most references to the growth of corals and mollusks. They are by many writers said to get their lime (for coral and shell) *from the sea water*. This I deem *very* misleading. *Plants* seem the only beings able to assimilate *mineral* matter. Even the lime, iron, etc., which may be in solution in the water an animal takes in, does not appear to be utilized as *food*, to become part of the animal. The plant alone can do that, and then the animal

Show slide or drawing of foraminifers. Tell of the deep-sea ooze now found (Le Conte, p. 453, or Dana, p. 131, etc.), and then give specimen of chalk and compare it with slide or drawings showing how it appears under the microscope.

Nummulitic limestone will be of interest (see Le Conte, p. 485), from the great abundance and curious shape of the little shells.

How many ways have we now found of making solid rock from the *lime in solution*? (By CO_2 , coral, shells of mollusks, and foraminifers.)

Call attention to the immense beds of limestone and chalk which are found, and try to give some idea of the work these minute animals have done in mountain making.

Silica gathered from the water.

Next show slides of *sponge spicules* and polycistines. These are of *silica*, although most other animals have limy skeletons.

Plants that have helped are the minute **diatoms** (show slide). These little plants, having skeletons of silica, live in the sea, and, dying, drop their tiny shields among the chalk shells, sponge spicules, and polycistine shells on the deep-sea floor, where they aid in making the thick beds of chalk.

eats and appropriates the mineral matters needed for its growth from that *stored in the plant*.

We do not find animal life preceding plant life, and herbivorous (plant-eating) animals must have existed before carnivorous (flesh eaters).

The sea abounds in minute forms of vegetable life (Dana, p. 135), and on these feed the minute animals which serve as food for the corals and shell-bearing mollusks. Hence not only guard against calling the coral animal "an *insect*," or talking of its "building" islands, but also avoid even the *inference* that they take the lime *directly* from the water.

At times beds of diatoms are found, forming *diatomaceous earth* (show specimen of the earth, and read of them in Le Conte, p. 484, and Dana, pp. 135, 496, 633, 634).

Flint and Chert.—These minerals are found in the shape of nodules in beds of limestone and chalk (see Le Conte, p. 452, ff.).

When thin slices are examined under the microscope they often show the fossil skeletons of minute diatoms, sponge spicules, etc., scattered through the hard flint. How could they have got there?

It is supposed that alkaline water has dissolved the minute shields of diatoms, etc., scattered through the chalk or limestone, and deposited the silica again in these nodules of flint and chert, somewhat as the iron has been gathered from the sands and gravels.

Higher plants than these diatoms have also done much rock making, but in a very different way.

Living plants allied to these ancient ones will be first examined. Give specimens of lichens, ferns, lycopods (club moss), equisetum, and conifers.

Review previous botanical work on these, learning their characteristics, mode of growth, and habitat.

Where do most of these grow? (Wet, marshy ground.)

Will they all burn when dry?

What is it in them that burns? (Carbon and hydrogen.)

Where does the plant get its carbon? (see Step XXIII, Morning-Glory). (From the air.)

In what shape must carbon be to exist as a gas? (CO_2 .)

Do all plants when burned leave an *ash*? (Yes.)

What color is it when well burned? (Gray.)

Where did the ash come from? (The "earth food" of the soil.)

What besides air and earth food do plants need for growth? (Heat and light.)

How will plenty of heat and moisture (as in the tropics) affect the *rate* of growth? (Rapid.)

Will the results of this rapid growth be spongy, or dense, tissues?

Compare a cornstalk and hickory stick. (Spongy and soft.)

Are the plants we have in hand most like the corn, or the hickory?

Are they then suited to rapid growth? (Yes.)

Do they bear bright-colored or fragrant flowers? (No.)

Do they bear *spores*, or true *seed*? (Only the pine has a true seed.)

Are these spores few, or many? (*Very* numerous.)

Where does a post or pile rot most quickly? At surface of ground or water.)

How about the portion *always* wet? (Decays little, if any.)

Can you give any illustrations of this? (Cedars fallen in swamps, water-logged wood, remains of trees, etc., in peat swamps and deltas; see Le Conte, pp. 133-136.)

What is a peat swamp? Of what plant is peat mostly formed?

What family of plants does sphagnum belong to? (Mosses.)

Are these mosses found among the coal plants? (No.)

What do most plants stand and grow in? (Soil.)

What makes soil *black*? (Decay of the plants that have grown on it.)

Where did these pieces of black shale (No. 43) come from? (Coal bin.)

How did they get among the coal? (Shale is found *below* all coal seams.)

Who can think what it was once ? (Earth.)

When burned in the furnace it becomes—— ? (Whitish.)

What colors it black ? (Carbon.)

Coal.—Above it lies a bed of—— ? (Coal.)

See this piece of coal. What caused these lines and impressions on it ? (Plants.)

Here is a bit of coal magnified (Le Conte, p. 341, or a slide).

What does the coal seem to have been made of ? (Plants.)

How are stratified rocks, shale, sandstone, coal, etc., formed ? (In water.)

Now show pictures and fossils of the coal plants and period, and then rapidly run over again the series of questions on *living* plants and see how much light they shed on the formation of coal.

What fossil does the modern fern most resemble ? (The ancient fern found in coal.)

Which fossil the lycopod ? (Lepidodendron.)

Which the equisetum ? (Calamites.)

These, then, were the plants largely concerned in making coal.

Where did the carbon come from ? (The air.)

If, as Laplace teaches, the earth were in a *melted* condition, where would all the carbon now in trees, coal, etc., be ? (In the *air* as CO_2 .)

Could man, or the air-breathing animals, live in such air ? (No.)

What way did the limy water of the early oceans remove the CO_2 ? (Made limestone.)

What way do we next find to further purify the air ? (Plants decomposing the CO_2 , keeping the carbon and returning the oxygen.)

What do we find overlaying the coal seams ? (Shale and other stone.)

Of what use was this covering up? (Compressed the soft vegetable fiber into compact coal and prevented waste.)

It is very expensive and difficult to dig as deep as we do for coal.

What *advantage* is there in such a covering? (Protected from burning up.)

METAMORPHIC AGENCIES AND THEIR EFFECTS.*

We have noticed the proofs that the earth was once much hotter, and consequently *larger*, than it is now. As it cooled the rocky outer crust would be obliged to continually adjust itself to the contraction of the heated interior.

Would these changes be sudden, or very gradual? (Gradual.)

Would the rigid outside be too large, or too small? (Too large.)

What shape was the crust? (Like a hollow globe, everywhere *arched*.)

How do the stones in an arch distribute the weight on them? (By thrusting outward as well as downward. The stones at the top have the most outward thrust, and those at the ends of the arch the most downward thrust.)

Would this pressure in a globe be chiefly a *down*, or a side-to-side (lateral), thrust? (Lateral.)

Now think of this with care.

What would result from this *tremendously* heavy crust slowly adapting itself to the contracting interior? (**Enormous pressure**, resulting in a *wrinkling* of the crust, with the necessary *cracking* and *slipping* of the rocks.)

As this land slowly came near the surface of the

* See Step XLII, § 12, etc.

oceans, what would the waves do? (Grind rocks to pieces.)

As the land arose above the sea, what would carry on the work of soil making? (Rain, sun, atmosphere, etc.)

Where would much of these fragments go? (Wash into the sea.)

So, for vast ages, we believe, this first formed land went on slowly rising and at the same time being cut down by the waves, rain, air, and other agencies, and the ocean filled.

Through the cracks formed in the rocks must have welled up great **floods of lava**. Meeting the waters of the ocean in some cases—what would happen to the lava? (It would crack into pieces and the waves quickly pulverize it.)

If it flowed out upon the land? (It would rapidly disintegrate, and be added to the deep beds of sediment in the ocean.)

While in these ways the first continents were being torn down, a change was taking place in the *rocky bed* of the oceans, over which all this gravel, sand, and mud had been piled.

As we dig down into the earth how does the temperature vary? (Becomes hotter.)

If we cover up the earth, as in glacier making? (The heat increases.)

Now, as thousands of feet of sediment are carried by the water and piled in wet beds on the ocean floor, how about the temperature of the original rocky bottom? (Rises.)

As these beds become thicker the temperature must rise till at last the **rocky bottom softens**.

Here, off the coasts of the land, we then have a softened rocky bottom overlaid by wet beds of sediment, all under the same tremendous side-to-side squeeze or thrust.

Can you think what will happen? (These soft beds will be slowly **mashed together** from side to side.)

Slate has been made in this way from——? (Shale.)

As their horizontal extent is compressed, what must happen to their **thickness**? (**Increases.**)

And so, as time goes on and the old land is washed into the sea, a **new continent** or mountain chain slowly rises from the waters.

Where will this new land lie? (Along the shores of the old land.)

What rocks will it contain? (Conglomerates, sandstones, shales, slates, and limestone.)

As these emerge, how will they in turn wear away? (Waves, rain, etc.)

The earth's crust is *growing smaller* all the time, and so the *whole* surface can not be rising at once. Hence, as this new wrinkle grows, what must happen to the old wrinkle? (Stops rising, or perhaps sinks.)



FIG. 10.—Amygdule filling agate.

Will the old or the new land, in the end, be highest? (New.)

How does it come to be that so many mountain chains are *parallel* to each other and the coast line? (Successive emergences along the old coasts.)

What will cause most of the ridges, peaks, and valleys? (Erosion.)

Wonderful as this mountain making is, there

are other important results from the same causes.

Veins.—Hot water, probably from the wet, heated beds of sediment we have spoken of, is constantly find-

ing its way through the cracks made by the wrinkling of the crust. This heated water often contains acids or alkalis in solution, which enables it to dissolve quartz or metals from the beds it was in, or the walls of the crack through which it flows.

Melaphyre is a rock which has been changed by hot water.

Amygdaloid is a rock whose cellular cavities have been filled from the minerals removed by such water. What rock was it once? (Lava.)

Agates are large amygdules of differently colored quartz left by such water as it circulated through and cooled in cracks and cavities.

Geodes are cavities in rock bathed in waters containing silica from which the beautiful crystals have grown.

Gypsum sometimes is found among limestone, and it is supposed has been caused by acid water turning the calcium carbonate to calcium sulphate.

Geysers are caused where water containing silica comes to the surface as a spring. Little by little the silica is deposited in the crack and about the opening till it is so closed that the circulation (convection) is impeded and the water forced violently out at intervals (see Le Conte, pp. 94-103).

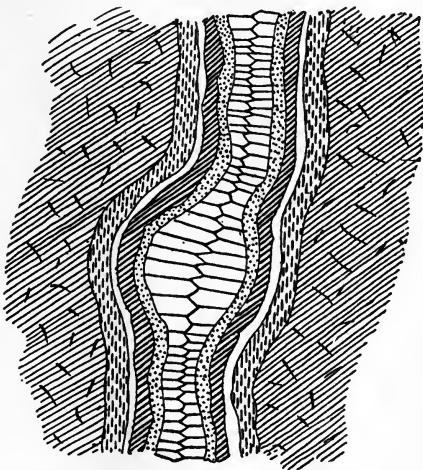


FIG. 11.—Vein filled with quartz.

Siliceous tufa, or geyserite, is made about hot springs and geysers. As time goes on these cracks through which the water rises become filled up by the formation of a *vein*. (Class draw Figs. 10, 11, and 12.)

Not only do these contain agate and many of our most beautiful crystals, but they also contain much of the lead, copper, gold, silver, tin, and other valuable metals and minerals, so that veins are of *great* importance to us. Some of these things are illustrated in the diagrams.

Earthquakes.—Glass is brittle, still a rod or sheet of it will bend some before the sudden snap with which it breaks. So rock, in the crumpling of the crust, keeps giving a little to the strain, and at last suddenly cracks with a shock which we call an *earthquake*.

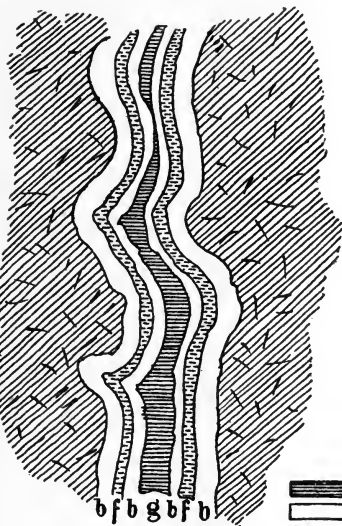






FIG. 12.—Metalliferous vein.

- | | |
|---|------------|
|  | Galena. |
|  | Baryta. |
|  | Feldspar. |
|  | Wall rock. |

As to the terrible effects of such shocks the books will tell.

Faults.—When these cracks occur, one side or the other is apt to *slip* up or down. (Draw a diagram of one from some work on geology.) These are very perplexing to miners, as they find a coal seam or ore vein suddenly ending, and where it has gone to is the question.

Heat.—As the rocky layers slip over each other not only do they get displaced, but what also results from rubbing things together? (Heat.)

If the rubbing is done by *very heavy* masses, how about the heat? (Very great.)

This will then heat the rocks near the crack.

Dikes.—At times melted rock flows up through the cracks in the rock instead of hot water (see diagram 1 in Step XLIV). This melted rock may be forced between beds of limestone or shale or flow out upon the surface. In either case, what will happen to the adjoining rocks? (Be heated.)

Just where this melted rock comes from we do not know, but have many reasons for thinking that the cooking of the lower sediments in the very hot water which must be there so softens the sandstones and shales as to form a thick liquid, which the immense pressure of the overlying beds, and perhaps deep oceans, forces up through the cracks as lava. However this may be, we do find that *crystallization* can take place, and the **fragmental beds become** changed to **crystalline** rock, or are firmly cemented by the solutions of mineral in the water.

METAMORPHISM.

All this dissolving out or filling in by the heated water, and heating by sliding, by dikes, or from the interior, causes a *change* in the rocks, and **such changed rocks are called metamorphic.**

Some common illustrations will aid in understanding this.

Gray clay, when heated, becomes——? (Red brick or tile, as the siderite in it becomes hematite.)

Black shale or limestone burns——? (Red or white, according as there is or is not iron in it.)

Coal, heated in gas retorts——? (Becomes hard, porous *coke*, *tar*, and *gas*.)

Sand, mixed with lime or alkali? (Fuses to a glass, and crystallizes if slowly cooled.)

Give the class the **rest of the specimens**.

Under these conditions of highly heated water and great pressure, **conglomerates** become *very* firm and hard.

Sandstones become——? (Quartzite.)

Shales and **slates** become (according to what they contain) mica, hornblende, chlorite or talcose **schists**, each known by the principal mineral composing it.

Are schists thick, or thin, bedded? (Thin.)

If thick bedded, such rocks are called **gneiss**.

If all trace of bedding is gone, and they seem unstratified, they are called **granite**, **syenite**, etc., the same as rocks we have met before.

Serpentine is formed by the alteration of other minerals, and when it occurs in limestone we have the beautiful green veining of some marbles (*verde antique*).

Limestones and **dolomites** become changed to crystalline.

Marbles.—These are black (from the charring of organic matter) or brown (from limonite) if the heat is gentle and water present, while the dry heat from dikes or friction turns the blacks to white and browns to red.

Iron forms an exceedingly interesting series as seen from this standpoint. First found scattered through the rocks as a part of the iron-bearing minerals augite, hornblende, mica, etc.; with the decay of these and the action of carbonated water, it goes into solution as siderite, to be gathered and deposited in the same state if organic matter is present (peat bogs, coal seams, and some clays), or changed to limonite if exposed to the air.

If, now, these masses of gathered ore are subjected to *heat*, the siderite becomes **brown (limonite)**; as the heating continues and water is driven off the brown changes

to **red (hematite)**; and if the heat is greater, this finally becomes **magnetite**, just as iron occurs in lava.

Coal also forms an interesting series.

The original vegetable matter is softened by water, and then the pressure aids in turning it into beds of soft coal. The heat of metamorphism now changes this into the hard, lustrous **anthracite** (a natural coal), and in the process vast quantities of "natural" gas are driven off.

Petroleum and **bitumen** may be formed at the same time, as tar is in gas making; but there are reasons for thinking these have come from the heating of such *shales* as contain plant and animal remains (black shale, etc.). If the heat is carried still higher, some of these (anthracite, petroleum, bitumen, etc.) become **graphite**, and the lustrous, crystalline **diamond**.

This will end the course in Minerals and Rocks.

Review of Rocks.—Wrap up a set of the specimens talked of and procure maps, pictures, etc., as suggested at the beginning of this step, and have a thorough review.

In preparing the questions, follow the order in which the material was given and the matter discussed, introducing at the proper place questions about the things familiar to the child in every-day life, such as the following:

What may have been the cause of the Lisbon earthquake?

Why are the mountains of western North America in several nearly parallel chains?

Where does the oil in our lamps come from?

Give the history of the graphite in your pencil?

Of the slate you write on?

Why are bricks red?

What was this white piece of clinker from the furnace?

Is the marble of the mantel of more interest to you? Why?

Where did the beautiful crystals probably form ?

How do crystalline garnets, etc., come to be in schists ?

Give us the history of that coal in the hod.

Of this diamond. This iron ore. The mended crack
 { in the stone.

The class might help think of things about them which are connected with lime, coal, and metamorphic rocks.

Review of the Whole Series of Lessons.—The great thing here is to spread the whole work out for the encouragement and help of the pupils and their friends. If several grades or schools are at work on different steps at the same time, let each class make up its own **exhibit**, but have all in one room, and let the pupils have the pleasure of showing their friends about and telling them the wonderful things they remember. This will be time *well* spent, and should be one of the “events” of the year, to which the classes and parents will look forward with pleasure.

Plan for Exhibition of Work done in Minerals and Rocks.—1. Table of sorted metals.

2. Table of sorted minerals.

3. Table of sorted rocks.

4. Making of rounded stones illustrated.

5. How sharp stones came to be.

6. Metals and their properties.

7. Molecules illustrated.

8. Crystals, and how they grow.

9. Minerals.

10. Rock making, physical agencies.

11. Rock making, organic agencies, and metamorphism.

My arrangement of material, experiments, maps, charts, etc., has been as follows :

A long table, slightly slanting toward the front, or in steps, was arranged, and plain labels neatly printed by

the class for each specimen, and large ones for the principal divisions or sections. The specimens were then ranged, from back to front, in six series, representing as nearly as possible the *gravel, sand, clay, iron, lime, and carbon* series.

MODEL EXHIBITION TABLE OF ROCK MAKING.

Section I.—Eruptive and Dike Rocks.

Glass. Slags. Pumice. Cellular lava. Obsidian. Felsite. Basalt.
Trachyte. Granite and Diorite.

Section II.—Leveling Agencies.

Rock with cracks.	Glaciated rock.	Water.	Rock with lichens.
Rock split by ice.	Glacier tool.	CO ₂ .	Minerals etched by roots.
Rock split by roots.	Mixed material.	Crushed	Rusted pyrite.
Expansion bar.	"Geo. Codfish."	rock.	Pyrite in coal.
Heat and cold.		Red clay.	Swelled iron sulphate.
		Gray clay.	Air-slacked lime.
			Distorted brick.

Section III.—Sediments and Sorting.

Gravel.		Sand.		Clay.	
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Illustrations of overlapping deposits ; lake filling ; deltas, etc.

Section IV.—Solutions deposited (Chemically Formed Rocks).

Scale.		Siderite.	
Stalactite.		Bog iron.	
Stalag- mite.		Iron test.	
Mexican "onyx."		Salt.	
Oölite.			
Limestone			
Dolomite.			
Gypsum.			
House plaster.			
Lime test.			

Section V.—Fragmental Rocks.

Conglom- erates.	|	Sand- stones.	|	Shales.	|
Breccia.	|		|		|

Section VI.—Modern Relatives of Ancient Plants and Animals.

Shells.	Diatoms.			Lichens.
Corals.	Sponge			Ferns.
Foramini-	spicules.			Lycopods.
fers.	Polycis-			Equisetum.
Coccoliths.	tines.			Conifers.

*Section VII.—Rocks formed by Plants and Animals
(Organically).*

Fossiliferous lime rock.	Diatom-earth.			Sphagnum and peat.
Nummulitic lime rock.	Flint.			Black shale.
Chalk.	Chert.			Soft coal.
				Fossilplants

Section VIII.—Metamorphic Agencies illustrated.

Arch (lateral pressure).	Wrinkles in	{ cloth—tallow } { —clay—lard }	Cracked and rubbed rocks.
Diagram of upheaval.	Hot water.		Heat (dry).
Melaphyre.	Geysers.		Earthquakes illustrated.
Amygdaloid.	Geyserite.		Faults.
	Veins.		Dikes through rocks.
	Crystals from veins.		Black shale burned white.
	Agates.		Red brick.
	Geodes.		
			Coal heated becomes coke, tar, gas.

Section IX.—Results of Metamorphism.

Firm.	Gypsum.	Quartzite.	Hematite.	Slates.	Anthracite.
Conglomerates.	Marbles:		Magnetite.	Mica schist.	Petroleum.
Serpentine.	Brown,			Hornblende schist.	Natural gas.
	Red,			Talcose schist.	Graphite.
	White.			Chlorite schist.	Diamond.
				Gneiss.	
				Granite.	

Section X.—The Earth of To-Day fitted for Man.

When all is ready, or at the proper time, send out *invitations* to the parents and friends to an exhibition that I am sure will prove enjoyable.

Notebooks, diagrams, etc., made by the pupils should also be exhibited at this time.

Material put away.—See Step XXXVII.

Results of the course in Minerals and Rocks.

Especially the training of the power of decision.

An introduction to chemistry and physics.

A great field of knowledge opened up and the way cleared for the profitable study of geology, etc.

An interesting avocation made possible.

In the nine-year course as outlined, 342 exercises have been arranged, taking about 150 hours of school time, or *one sixtieth* of the whole.

Considering the educational value of the above results, and that the tedium of school confinement has been relieved and other work better done because of interest in this, it has been time *well* spent.

STEP XLIX.—ANIMALS.

GROUPS OR CLASSIFICATION.

Object.—Familiarity with a number of types has now placed the pupil in the position where he can make intelligent comparisons and detect those resemblances and differences which are the basis of true classification. Let this be **individual work on specimens**, as only so can the most valuable results be gained.

Time.—About thirty to forty lessons of thirty minutes each at any time of the year.

Material.—Quite a stock will be required to do effective work and keep a class of twenty to twenty-five all busy. The gathering of this must be begun at least a year in advance, or a high price be paid, and even then the material will not be in proper shape. The teacher will also lack the inspiration which comes from personally made collections.

The following material has proved satisfactory in years of use, but can be varied without serious loss in efficiency. Cheapness and durability must always be important items in selecting. **Have ten each** of the following:

Red coral (precious) fragments.

White coral (madrepore) fragments.

Collection of corals to sort. (These collections should in each case have *several* representatives of the types studied and also of other types, so that the pupil may have a little practice in using his newly discovered key to the classification.)

Earthworms, each in glass vial (of four-per-cent formaline solution).

Leeches, each in glass vial.

Sea worms (*Nereis*, etc.) in vials.

Starfish (common sorts, as *Asterias*), small, dry.

Serpent stars, small and dry.

Collection of various starfish to sort.

Sea urchins (*Echinus*), spineless tests, dry.

Cake urchins (*Clypeaster*), small, dry tests.

Collection of various echinoderms to sort.

Sow bugs (*Oniscus*), in vials.

Crayfish, injected (see directions in Step IX for making dry, yet flexible material for study).

Centipeds, some native form, in vials.

Julius worms, in vials.

Locusts, on pins, with wings of one side set, larvæ in vials.

Libellula, on pins, with wings set, larvæ in vials.

Squash bugs on pins, larvæ in vials.

Ant lions (caddis fly or lace fly), on pins, larvæ in vials.

Meat flies, on pins, maggots and pupa cases in vials.

Beetles (any large common kind), on pins, grubs and pupæ in vials.

Bees (or wasps), on pins, larvæ and pupæ in vials.

Butterfly, wings set, caterpillars and pupæ in vials.

Collection of several of each order of insects, to sort.

Oyster, paired shells.

Fresh-water clam, paired shells.

Salt-water clam (*Venus*, etc.), paired shells.

Collection of bivalves, in paired shells, to sort.

Gasteropods, with canal to lip (*stromb*, *murex*, etc.).

Gasteropods, lip entire (*limnœa*, *helix*, etc.).

Collection of many univalves to sort.

Perch, small and fresh, mounted or in formaline fluid.

Sturgeon or garpike, same state.

Goldfish, salmon, or pickerel, same state.

Spotted (or tiger) salamanders, in formaline fluid.

Frogs and tadpoles, fresh or in fluid.

Lizards or chameleons, fresh or in fluid.

Snakes (small), fresh, in fluid or mounted.

Alligators (small), in fluid or mounted.

Turtles, mounted, injected, or fluid.

Blackbirds, skins or mounted.

Collection of bird skins for comparison with black-bird and each other.

Mammals—rats, mice, squirrels, bats, and domestic animals—can usually be had fresh or stuffed, and markets will frequently supply material for comparative study.

The work on mammals must depend on the available material; in lack of any, omit.

Cost.—There will be 500 or more specimens in the above list, which will average about ten cents each, or \$50 for all. The depreciation will be about ten per cent each year of use, but the specimens brought in by interested pupils and a wide-awake instructor will ordinarily cause *gain* rather than loss. In any case, the cost is *very* small per pupil in comparison with the valuable training and added interest in wholesome things which is gained. Good work can be done with a smaller supply, a single specimen of some of the rarer animals sufficing, but the delay and loss of time to the pupils makes such saving highly expensive.

Store in Cigar Boxes.—These cost nothing, and rarely admit vermin. Label on the end, so as to stack them up on shelves and still admit of ready finding.

Vials and bottles of material in fluid can stand close together in coverless boxes or trays. Label them on the corks, as well as on the sides.

Books.—Morse's First Book in Zoölogy is still the best real aid for the cost. Orton's Comparative Zoölogy (1894 edition), Standard Natural History, Holder's Zoölogy, and Jordan's Manual of North American Vertebrates, are also helpful. Have ten copies each of Morse and Jordan.

Cards.—The material being gathered and needed substitution made, proceed to prepare the following set of cards to direct the individual work. These must be duplicated to ten in number, and written *very* plainly, or, better still, printed :

No. 1. Find the resemblance and difference between red coral and white coral, recording the same in your notes.

No. 2. Classify the collection of corals into two sets to agree with No. 1, and bring to the instructor for approval.

No. 3. Compare the three worms given (as with the corals).

No. 4. Compare two kinds of starfish, as in No. 1.

No. 5. Sort the collection of starfish, as in No. 2.

No. 6. Compare two kinds of sea urchins.

No. 7. Sort the collection of sea urchins.

No. 8. Find as many points of *resemblance* as possible between a starfish and a sea urchin.

No. 9. Compare a sow bug and a crayfish.

No. 10. Compare a centiped and a milleped.

No. 11. Compare a locust, a libellula, and a squash bug.

No. 12. Compare an ant lion, a fly, a beetle, a bee, and a butterfly.

No. 13. Arrange a collection of mixed insects according to the basis discovered in Nos. 11 and 12. In what points are they *all alike* ?

No. 14. Find *resemblances* between groups 9 to 12 inclusive by a study of a crayfish, a centiped, and an insect.

No. 15. Compare a clam shell and a snail shell (see Orton, p. 134).

No. 16. Compare a clam shell and an oyster shell.

No. 17. Compare a fresh-water clam shell and a sea clam shell.

No. 18. Arrange the collection of bivalve shells in three groups, corresponding to the oyster, fresh-water clam, and salt-water clam.

No. 19. Compare stromb and helix shells.

No. 20. Sort a collection of univalve shells into two groups corresponding to those of No. 19.

No. 21. Find resemblances between the clam, oyster, and snail.

No. 22. Examine this perch, dissecting carefully, and comparing with Orton, pp. 61, 83, 100, 107, 110, 135, 148, 158, 172, 184, 311, 312. Analyze by Jordan's Manual, and use the glossary for unfamiliar terms.

No. 23. Compare a goldfish, a perch, and a sturgeon. In what points are these three fish *alike*.

No. 24. Examine a frog. Use Orton, pp. 61, 82, 100, 108, 119, 126, 172, 184. Analyze by Jordan, and use glossary for new terms.

No. 25. Compare a frog and a salamander, and decide in what points amphibians are alike.

No. 26. Examine a snake. Use Orton, pp. 54, 61, 67, 68, 73, 82, 100, 108, 110, 118, 119, 135, 150. Analyze by Jordan, and use glossary.

No. 27. Compare a snake, a lizard, a turtle, and an alligator, and decide in what points reptiles are alike.

No. 28. Examine a blackbird. Use Orton, pp. 54, 62, 84, 100, 109, 110, 118, 137, 150. Analyze by Jordan, using glossary.

No. 29. Compare a blackbird, a duck, a hen (add other typical birds, if available), and decide on *resemblances*.

No. 30. Examine a rabbit. Use Orton, pp. 54, 62, 68, 70, 86, 110, 119, 136. Analyze by Jordan, and use glossary.

No. 31. Compare a rabbit, a cat, a cow, and yourself, and decide on points in which all are alike.

No. 32. Review notes on Nos. 22 to 31, and find points in which all are alike.

No. 33. From memory write as many points as you can in which *all* animals are alike.

No. 34. Make a study of the resemblances and differences between *plants* and *animals*.

THE LESSONS.

Notebooks and **pencils** should be had by each pupil; the book square rather than long (10 × 12 c.m.), and opening at the end.

Model Notes.—It is important that correctness and neatness shall be observed by all, and this can best be secured by a model at the beginning. See page 281 and proceed as follows:

1. Distribute the specimens of coral so that each pair of pupils may have specimens.
2. Place at the top of the blackboard (pupils place in notebooks):

Corals Compared.

Differences.

Resemblances. Points noticed. Red Coral. White Coral.

3. Under "Points noticed" list all things they can notice about the specimens, leaving space for after-thoughts below.

4. Then extend, in line with each point, such remarks as may be proper.

5. Examine these lists to see what are the *most noticeable* resemblances and differences, and underline such.

The page in the notebooks will then resemble this :

Corals Compared.

Resemblances.	Points noticed.	Differences.	
		Red Coral.	White Coral.
	Color.	Red.	White.
Branched.	Shape.		
	Surface.	Furrows.	Pits.
Hard.	Texture.	Solid.	Porous.
Effervesce = calcareous.	Acid test.		
In sea.	Home.		
About the mouth.	Tentacles (from pictures)	In eights, and fringed.	In sixes, and smooth.
In middle of top	Mouth (see pictures).		

Next, with the blackboard, help the pupils to head the pages of their notebooks to correspond with the cards. All is now ready for individual work.

Let the teacher be seated at a large table on which the material is handy, with one of the older pupils to assist during the starting.

Call up pupil A, and give the collection of corals and card 2.

To the next ten give card 3 and the three worms, and to the rest of the class card 4 and the two starfishes, and so on.

When A returns the corals, examine to see that the solid and porous kinds are separated, and, if right, give card 3 and the worms ; or, if none are in, give card 4 and the starfishes.

Whenever a pupil thinks he has thoroughly studied his specimens and recorded his observations, let him quietly bring book and specimens to the teacher, who will glance over the "resemblances" to see that the pupil has discovered those by which scientists group the

specimens, and over the "differences" to see that enough have been observed to identify each kind. A dash of colored pencil under these characteristic points will show the pupil the essentials on which classification is based, and he can be given the next thing unfinished—in this case, the box of corals to sort.

Two difficulties will here begin which will test the tact and good sense of any teacher. **First, how to prevent** the lazy and weak from **copying** the approved notes of the bright and quick. No reproof or punishment is of permanent value. My plan has been at the start to plainly point out the serious damage it is to the one who copies, and to stimulate a sense of pride and self-respect which will forbid helping or being helped. This, added to my request, has rarely failed, and when it has failed the pupil has punished himself beyond anything I could inflict, and he knows it. **Second, how to encourage** those whose "eyes see not," and who come time after time without having observed the essential differences and resemblances. That such should learn to be close observers is of importance in their life work, and is worthy of the most serious effort; hence **encourage** them in every way to try again, **but do not do their work for them**. It may be well in some cases to lay aside the material in hand and select something new till success has brought new courage and restored confidence. (Shells have proved helpful in this.)

Varying ability and knowledge will soon spread the class over sufficient ground, so that each student who has mastered one set of material can be supplied with the next thing his notebook headings call for, and the work will be easily carried forward by the well-informed and experienced teacher. Some pupils will develop almost the intuition of a Linnæus, and be inconveniently ahead of the rest. To keep such busy, and still reward energetic and thorough work, I provide side issues (open only to

those in advance of the rest) to occupy their time. These must be devised by the instructor in accordance with his equipment, etc. I give them my private and larger collections to examine (and find scientific names for the specimens), a compound microscope to examine sections of shells, scales, etc., have them find the percentage of lime in skeletons, and make a comparative study of scales, hair, and feathers; these are among my tried and successful devices.

When vertebrates are reached, such bright pupils especially enjoy finding the names of specimens by Jordan's book. **Class reviews** can be held from time to time, and by rapid questions or descriptions the characters of some one class of animals (which all have completed) may be emphasized.

Results.—This work will delight the pupils and surprise the teacher if approached in the proper spirit. Pupils who seemed incapable of learning from books have in this shown great acuteness, and received a new stimulus for less attractive subjects, while all have gained in rapid and accurate observation and acquired zest for a healthy avocation.

GENERAL CONCLUSION.

In the nine years' work outlined, about 350 exercises, consuming 120 hours (one seventy-fifth of the 9,000 or more a child usually spends in school up to the age of fifteen), have been given to these animal lessons.

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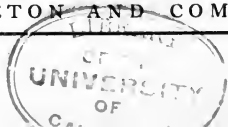
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