A-2: Getting started with notebooks

Schedule	5 minutes: Introduce activity 20 minutes: Groups discuss scientists' notebooks 25-35 minutes: Whole group discussion

Materials	Chalkboard & chalk, whiteboard & dry-erase markers, or large easel paper & markers. Handout with group instructions and excerpts from scientists' notebooks

Set-up	Arrange chairs/desks to flexibly move from small groups of 3-4 to a whole-class horseshoe with a chalkboard (or whiteboard or easel) at the end.

Getting started:
We introduce notebooks on the first day of class, after discussing the syllabus and goals of the course. Say something like:

> *In this class, you will be asked to keep a notebook. Notebooks in this course will be modeled after the notebooks used by practicing research scientists.*
>
> *You will be divided into groups and each group will be given a set of excerpts from the notebooks of famous scientists. Your group's job is to examine the scientists' notebooks and describe the way he took notes and organized information. We will use your group's observations to generate guidelines and grading criteria for the notebooks you will keep in this course.*
>
> *As you work, write down your observations on a sheet of paper. We will not be collecting these notes - they are simply to keep track of your ideas.*

Once students understand the overall plan, divide students into groups of 3-4 students, pass out one handout to each group, and give students time to work.

Monitoring group work:
As students work on this task, it is generally sufficient to stand back and allow students the opportunity to run their own groups. Loosely monitor the groups from afar to ensure that they understand the directions, are on-task, and are engaged. For instance, be sure that students are focused on the general features of the notebooks rather than the specifics of the science that is being done.

Students will naturally have questions about who these scientists are and the scientific context that these notebook pages fit into. If you find yourself fielding these types of questions or after 5-10 minutes when all the groups have had a chance to scan the example notebooks, then it may be helpful to stop the conversation briefly to give students some background information about the scientists and what they were working on.

- Fig. 1: Sir Charles Darwin (1809-1882) - Darwin was a naturalist who is famous for his 1959 publication of *On the Origin of Species*, outlining the theory of evolution by natural selection. Evolutionary theory unifies the life sciences and provides an explanation for the diversity of life on Earth and how they came to be. The excerpt is taken from Darwin's Notebook B, written in the years immediately following his voyage on the *Beagle*. In it, he sketches the relationships between related species in what is now known as the "tree of life".

- Fig. 2: Alexander Graham Bell (1847-1922) - Bell was a scientist, engineer, and inventor whose investigations on sound resulted in the invention of the first telephone. The excerpt describes the first successful telephone call between Bell and his assistant, Thomas Watson, between two adjoining rooms. Bell also experimented widely in other fields and is credited with the invention of the metal detector and with extensive research into medical treatments for the deaf, hydrofoils and aeronautics.

- Fig. 3: Albert Einstein (1879-1955) - Einstein is known as the father of modern physics for his theory of general relativity. At the heart of this theory of Einstein's field equations, a set of ten equations that describe how the geometry of space and time are influenced by whatever matter is present. This excerpt is taken from one of Einstein's notebooks from 1928 in which he is thinking about these field equations and trying to understand some of their implications and extend it to explain electricity and magnetism.

- Fig. 4: Manhattan Project Notebook (1942) - The Manhattan Project was a secret scientific and military project that was launched when the United Stated entered into World War II. It's objective was to build an atomic bomb before the Germans did. The excerpt is from an experiment directed by physicist, Enrico Fermi documenting the progress of the first controlled nuclear reaction. The data records how the nuclear reactor responded to moving cadmium control rods that prevent the chain reaction from spiraling out of control. "We're cooking!" was the reaction of the scientists when it became clear that the experiment was a success. Many other world reknown scientists (a total of 21 eventual Nobel Laureates) contributed to this massive collaborative effort including J. Robert Oppenheimer, Albert Einsten, Niels Bohr, Richard Feynman, Ernest Lawrence, and Emilio Serge.

- Figs. 5 and 6: Linus Pauling (1901-1994) - Pauling was a chemist and peace activist who earned two Nobel Prizes in his lifetime. He worked in many different fields ranging from biology (to deduce the structure of hemoglobin and DNA), to chemistry (to understand the nature of chemical bonds), to physics (to understand the structure of the atomic nucleus). Fig. 5 is taken from one of his last notebooks after which he lay awake at night and realized a mistake he had made concerning the chemical structure of bottinoite, an obscure blue-green mineral that was discovered in the 1990s. Fig. 6 is taken from his much earlier work in the 1930s and 40s to understand the structure of hemoglobin.

If it is necessary to work directly with a group (they seem to have finished well before other groups or are clearly not on-task), offer an observation or question to reignite the group's discussion. For instance:

- *Take a look at the last question on the instruction sheet: "What is a scientists' research notebook for?" What do you think?*
- *Who might read these scientists' notebooks? Why would they read them?*
- *Did you notice the little exclamations that the scientists made in their notebooks (Fig. 4 "We're cooking!")? Are there other little exclamations like those?*
- *Did you notice how Alexander Graham Bell's notebook pages read like a story?*
- *What criteria do you think should be required of your notebooks for this class? Make a list.*

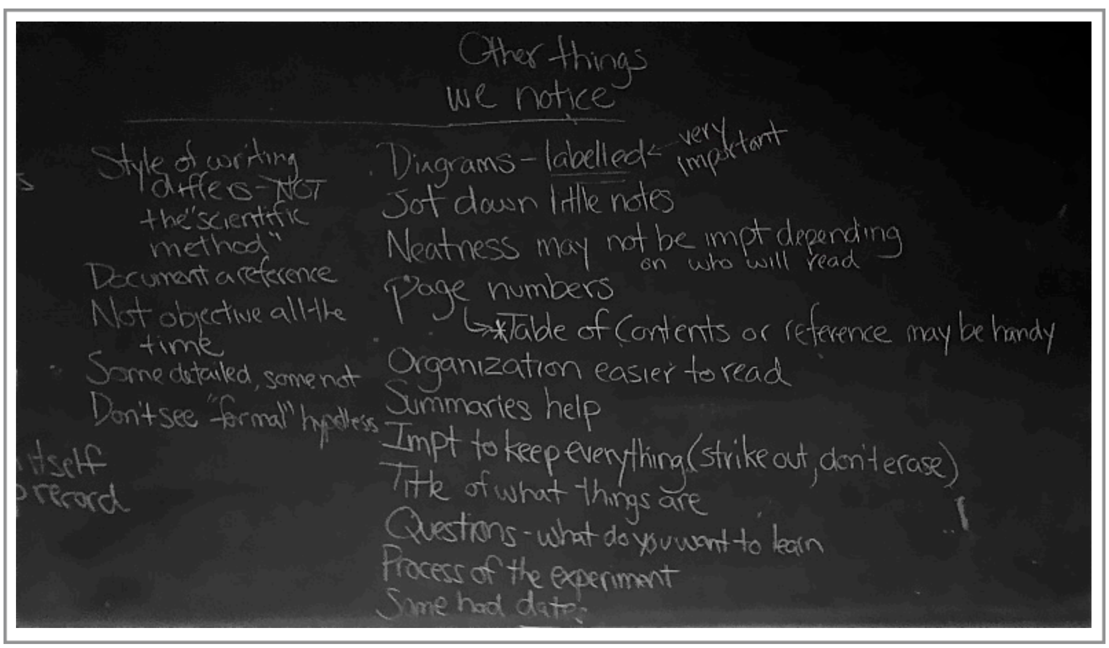
When it appears that groups have fully considered the questions on the instruction sheet and have a good set of notes, give students a 1 minute warning to allow groups to finish their conversations. Then, direct students to rearrange their seating into a horseshoe configuration facing the board.

Opening up discussion:

Part 1: Things we notice

Prepare for the group discussion by writing "Things we notice" on the board/easel paper:
To begin the discussion, you might say something like:

Okay-- it looks like most of you are done writing/have written a lot/have some ideas to talk about. So let's hear what your ideas are. I'm going to be taking notes on the board as you talk-- if you see me write down your idea and I have written it down incorrectly, let me know.



As students offer up their ideas, jot down a brief note or description of their observations. Your role in this discussion is merely to make sure everyone hears and understands each student's ideas and to record these on the board (like a brainstorming session). As with other class discussions in a course like this, these notes on the board serve as an index of the ideas that have come up in the conversation. They let students to know their ideas are heard and understood. These records will become useful later as you turn the discussion towards the purpose of a science notebook and the criteria students wish to require of their own notebooks.

The following observations are ones that we feel are notable in looking at these excerpts. In the conversations we have had with these notebooks, these ideas have been expressed in one form or another by our students.

- Personal expressions of creativity, excitement and individuality ("I'm astonished!")
- Sketches
- Organized (dates, page numbers, data organized in tables, lists…)
- Reflection/thinking analysis – not just what was done but why it was done and what it means
- Ability to go back and retrieve information (data and reflection/analysis alike)
- Writing is crossed out, not erased
- Questions about what this means and what else to try
- It is not the "5 step scientific method" format
- Some are more like a personal journal or story, others are more formal - each has a different "personality"

If the flow of ideas falters or subsides, encourage students to focus on one excerpt for a time (such as Fig. 2 or Fig. 6) and see what they see in that one entry. Or pick two different entries and see what is similar and different between them (such as Fig. 1 and Fig. 5).

Part 2: Purpose of notebooks

After assembling a fairly comprehensive list of observations, shift the conversation to the purpose of a notebook. Create a new heading ("Purpose of Notebooks") on the board or on a new sheet of easel paper to record students' ideas. For instance, you might say:

> *This is a great list of observations. What do these observations tell us about what a scientist's notebook is for? What is the purpose of them? Who reads them?*

Allow students time to brainstorm as they did before, drawing from their list of observations. It may help to categorize the list of "Things we notice" into whatever natural groupings students find.

In this part of the discussion, you will probably need to take a more active role in managing the conversation. The goal is to draw students' ideas together into a few general statements about what a scientists' notebook is for. However, you should expect some disagreement at times as the class negotiates its way to some consensus ideas. To direct a conversation towards consensus, it is often helpful to highlight similarities or differences between two students' ideas.

I think that both you and Amy are saying in different ways that notebooks are a place for scientists to keep track of his or her thoughts and questions so that they can be revisited and remembered later. Is that right?

I think you are saying that it is important for a notebook to be organized and legible so that other people can recreate a scientist's experiments. However, Johnny said that notebooks are just a scientist's personal notes and aren't meant for other people to read. What do other people think? Is there a way for a notebook to be both?

In general, we have found that after a bit of discussion and brainstorming, students identify two parallel purposes of a notebook. First, there is a more subjective, private side to notebooks. In many ways, this part of a notebook is like a personal journal that records a scientist's inner thoughts and ideas as they arise. It is a "brain dump", a place to record questions and "aha" moments, and sometimes has the feeling of a story that can be followed from beginning to end, with detours and diversions along the way. This part of a notebook may be messy and incoherent to the outside reader because, in this role, its audience is the scientist himself or herself.

There is also an objective, public side to notebooks. This part is intended for both the scientist and his/her colleagues who might need to look back on some data, reflect on past ideas, or recreate/build on previous experiments. It is organized with dates, page numbers, headings, and data tables to more easily find what one is looking for.

This conversation is less about brainstorming and more about coming to a class consensus about a notebook's purpose. We have found it to be helpful to jot down and keep a record on the board of *all* students' ideas under the "Purpose of notebooks" heading, and then, as the class begins to come to consensus, to designate a separate space (such as a boxed area on the board) for consensus ideas that summarize and consolidate several student ideas into one.

Part 3: Our notebooks

Once students reach some agreement on the purpose of notebooks, redirect the conversation to things that students want to require of themselves as criteria for their own notebooks. Create a new heading ("Our Notebooks") on the board/easel paper to record students' ideas. You might begin this part of the conversation with something like:

It seems that we are now in general agreement that the purpose of scientists' notebooks is _______________. As I mentioned before, you will need to keep a notebook in this class and I want your notebooks to be modeled after a scientist's notebook. What should be the purpose of notebooks in this class? What kinds of things are reasonable to expect from yourselves in creating a quality notebook?

Once we have a list we can all agree to, I will use your list to generate a set of grading criteria for your notebooks for this semester.

If you have a background in scientific research, you might share anecdotes of how notebooks were used in your lab, particularly any public role they filled - how other members of a research group used them and what expectations surrounded their use.

It should soon become clear that notebooks in this course serve a similar purpose to scientists' notebooks. There is however, an additional element that students' notebooks will be collected periodically and graded. Therefore, students' notebooks will serve the additional purpose of informing you about students' ideas and allowing you to assess their progress.

There may be some disagreement about specific, detailed requirements within the class. Should all pages be numbered? Do you always have to have headings, labels and captions? If these arise, redirect students to the bigger question of the purpose of a notebook and whether a notebook can still meet its purpose without page numbers and labels. For instance are labels and headings something that is usually helpful and should be present most of the time, but doesn't have to be there every time.

Concluding and creating grading criteria
Once students have a reasonably comprehensive list, it is fair for you to interject some other specific requirements that you have. For instance, if students have not brought up things that are critically important to you (such as making detailed observations or writing clear descriptions of an experimental set-up so that they can be recreated), then offer up your ideas to the class and get their agreement and buy in. Allow them the freedom to take your idea and adapt it (within reason) as they would with other students' ideas.

Logistical things (late policy, binder vs spiral notebook, how to make up absences, etc.) are your prerogative and can be introduced the following class period, after students' ideas have been shaped into a list of formal grading criteria. As much as possible, use the students' own language on the rubric. On the following page, you can see a copy of the grading criteria we devised one semester. We included space for each student to identify specific pages where we could find evidence that they met that criteria and for them to give themselves a grade in each area before they turn their notebooks in.

Tips for using notebooks:

<u>Time to write</u>

We have found in our own iterations of this course that students who do not participate much in group discussions often have incredibly rich notebooks, and are thus participating in the conversation through their writing. In contrast, those students who are very active verbal participants often lack any notes regarding the conversation.

For this reason, we have found that pausing class discussions periodically to give talkative students 5 minutes to put their thoughts down on paper can be helpful. In addition, for very talkative classes, the last few minutes of class can be reserved for silent writing to put down their thoughts from that period and organize their ideas for the next class.

<u>Getting to "why"</u>

Over the past few semesters, it has become clear that what students struggle with the most in keeping a notebook is not keeping detailed records of experiments and results. Rather, it is difficult for students to capture the reasons these experiments are being done in the first place and what the results they obtain mean.

Personal relevance: *These requirements are, in general, a measure of your personality as a researcher. Does your notebook demonstrate that you are reflecting, thinking, curious and engaged rather than simply going through the motions and copying down the data? Is your notebook clearly relevant to you?*		
requirement	**pages?**	**grade**
includes some notion of what you're thinking, expecting, and/or assuming		
includes some kind of questions about what you're hoping to understand/answer/show or a new question that your research has raised		
reflection and analysis of what it is you've observed, some notion of a "trajectory" of ideas and thinking (what you have *learned*)		
some obvious engagement, creativity, individuality and personal expression (for example, sketches, ideas, notes in the margin, careful attention to detail, organization, etc.)		
space to fill in ideas later and refer back to earlier questions and work		
Publicly useful: *These requirements are a measure of how useful your notebook is as a reference for others in following the sequence of ideas, experiments, and data.*		
requirement	**pages?**	**grade**
all pages are numbered, all days are dated		
labels are used to organize and inform (headings for different topics; labels on diagrams)		
clear descriptions, including diagrams with labels and procedures, of what you're doing to answer your questions		
detailed, accurate observations		
references to other classmates' work/ideas or outside readings are noted clearly		
corrections are crossed out, but not erased		

Usually experiments and observations in science are “theory driven”-- they help us rule out a model or offer additional support for a model. There is a clear reason, then, that these experiments are being done. For instance, one semester it became clear that some students thought light behaved like little bullets shot out of a gun and could therefore ricochet off of walls and bounce off of other light “particles” traveling in a different direction. This light-as-a-particle theory implied that two beams of light from two separate flashlights would strike one another and alter each other’s path. We tested it and the two beams of light did not interfere with one another.

In general, our students’ notebooks described the two flashlight experiment and noted the observation that the beams did not interfere with one another, but missed the connection to modeling. At best, students noted “I want to see if two beams of light will change each others’ path” not “I want to figure out if light is more like particles as Dee mentioned - where beams can bounce off of each other - or more like the ‘energy’ that Steven mentioned and just passes through another beam of light.” After the observation, students tended to summarize their findings as: “the two beams of light continued through one another without changing their path at all,” not: “now it is clear that light doesn’t act like bullets out of a gun. We need a new model. Perhaps...” In writing about science, we’ve noticed a similar tendency; writers getting so wrapped up in the experiment that they forget the bigger picture of why it matters for science.

To help students give more information about the “why”, whenever a critical moment arises and everyone understands the implications, give students 5 minutes to write at that time and prompt them to think carefully about why the experiment is important, not just the design of the experiment. At the end of the experiment, give students further time to write and reflect on what the results imply. Modeling this type of reflection in the whole class discussions helps students incorporate this type of reflection in their small group research time.

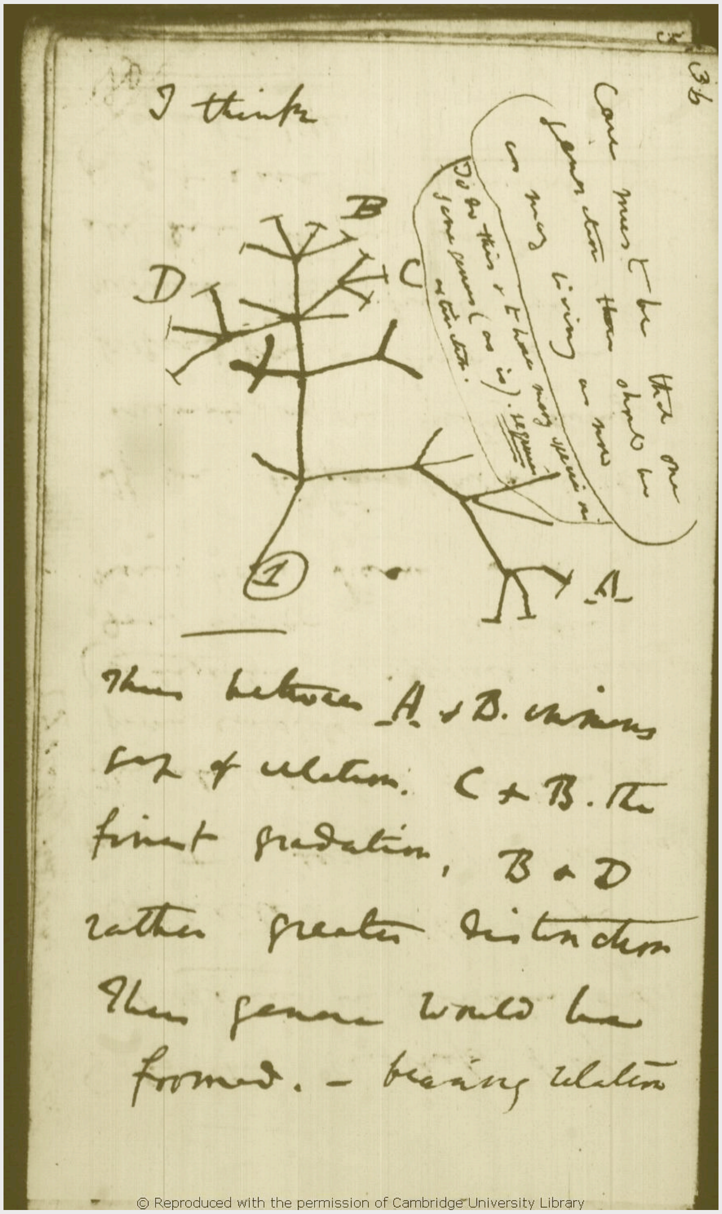
Scientific Inquiry
Scientists' Research Notebooks

On the following pages are images from several famous scientists' research notebooks-- the notebook used to keep track of ideas, observations and experiments as he worked. With your group, discuss what you notice about these notebooks. Do not describe the actual work the scientist did, but ways in which he took notes and organized information.

Below is a list of a few things you might notice, but be sure to generate more observations than just these:

- what does the page look like?
- does the scientist write down observations only, or interpretations of observations?
- are there procedures described?
- what is the style of writing? Personal, objective, colloquial, etc.?
- what similarities do you see between the notebooks? how are they different?
- how do these famous scientists' research notebooks compare to lab notebooks you have kept in other science classes?
- what is a scientist's research notebook for?

Keep track of your groups' ideas on the whiteboard you have been provided. We will generate a rubric with guidelines and standards for keeping a research notebook in this class based on the lists you have generated.



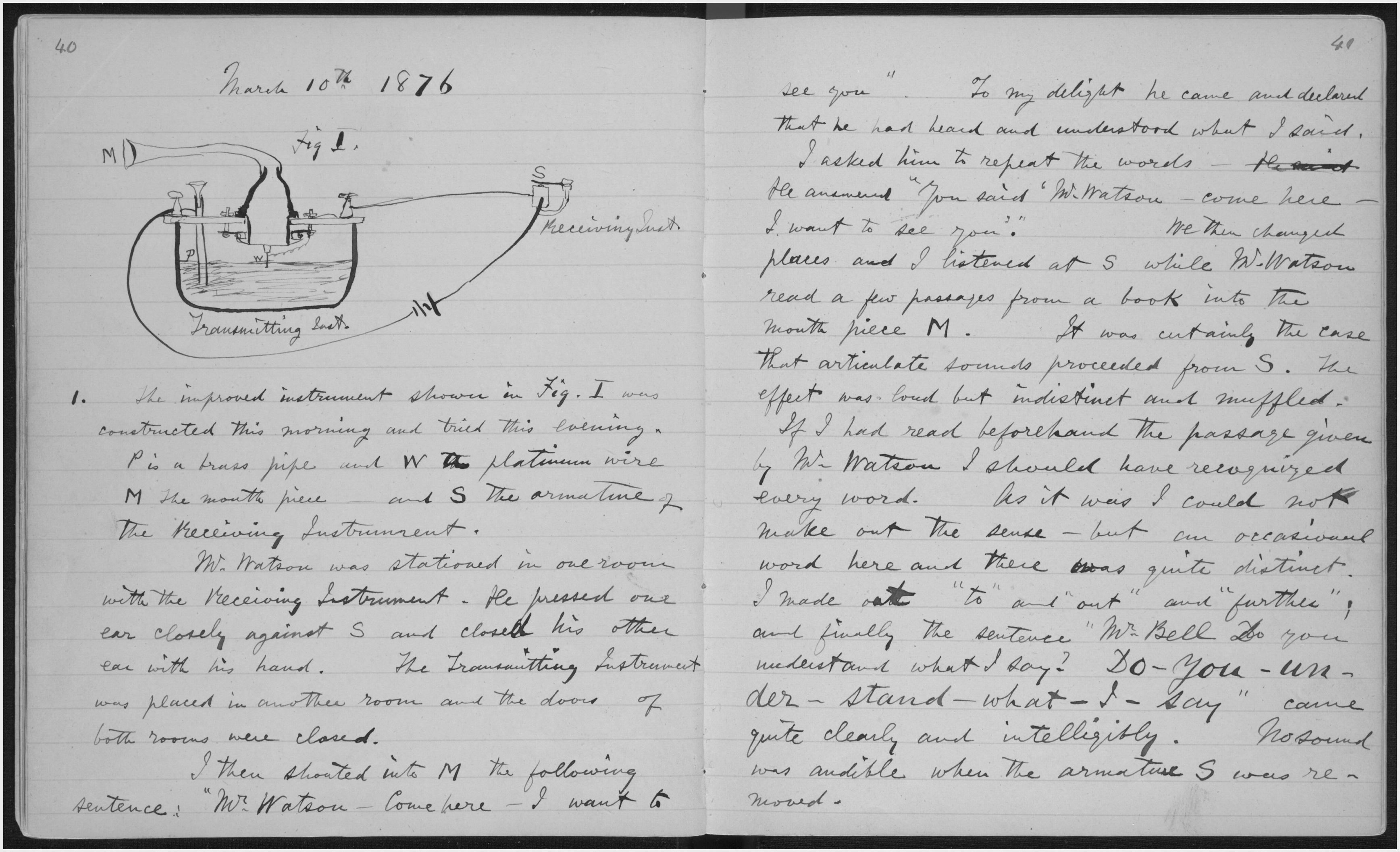
I think:

Case must be that [in] one
generation there should be
as many living as now.
To do this and to have [as] many species in
same genus (as is) requires extinction.

(Fig. 1)

Thus between A & B immense
gap of relation; C & B the
finest gradation, B & D
rather greater distinction.
Thus genera would be
formed, bearing relation...

Fig. 1: Sir Charles Darwin



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March 10th 1876

1\. The improved instrument shown in Fig. I was constructed this morning and tried this evening. P is a brass pipe and W the platinum wire M the mouth piece — and S the armature of the Receiving Instrument.

Mr. Watson was stationed in one room with the Receiving Instrument. He pressed one ear closely against S and closed his other ear with his hand. The Transmitting Instrument was placed in another room and the doors of both rooms were closed.

I then shouted into M the following sentence: "Mr. Watson — Come here — I want to

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see you". To my delight he came and declared that he had heard and understood what I said.

I asked him to repeat the words — He answered "You said 'Mr. Watson — come here — I want to see you.'" We then changed places and I listened at S while Mr. Watson read a few passages from a book into the mouth piece M. It was certainly the case that articulate sounds proceeded from S. The effect was loud but indistinct and muffled.

If I had read beforehand the passage given by Mr. Watson I should have recognized every word. As it was I could not make out the sense — but an occasional word here and there was quite distinct. I made out "to" and "out" and "further"; and finally the sentence "Mr. Bell Do you understand what I say? Do-you-under-stand-what-I-say" came quite clearly and intelligibly. No sound was audible when the armature S was removed.

Fig. 2: Alexander G. Bell

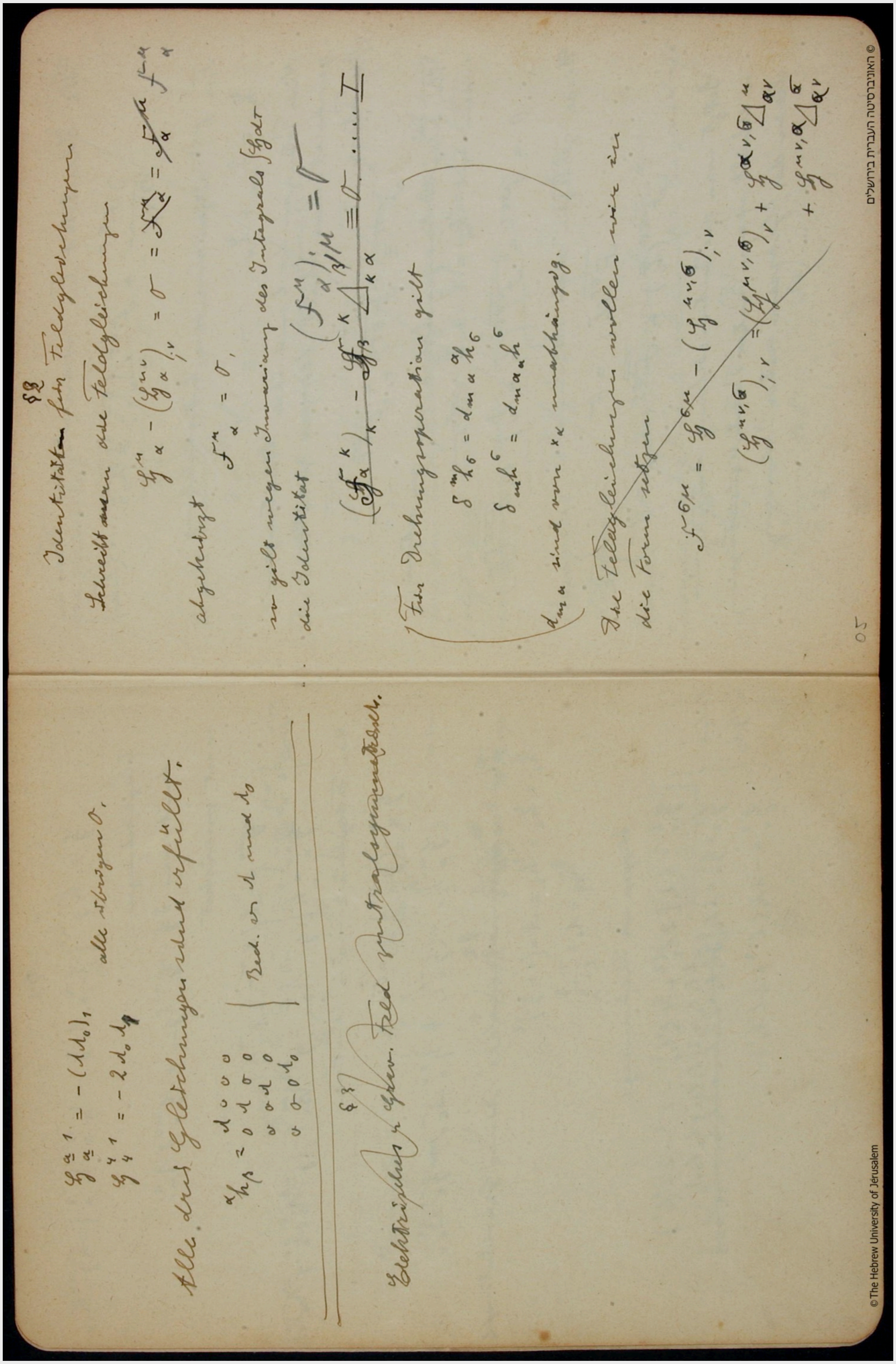


Fig. 3: Albert Einstein

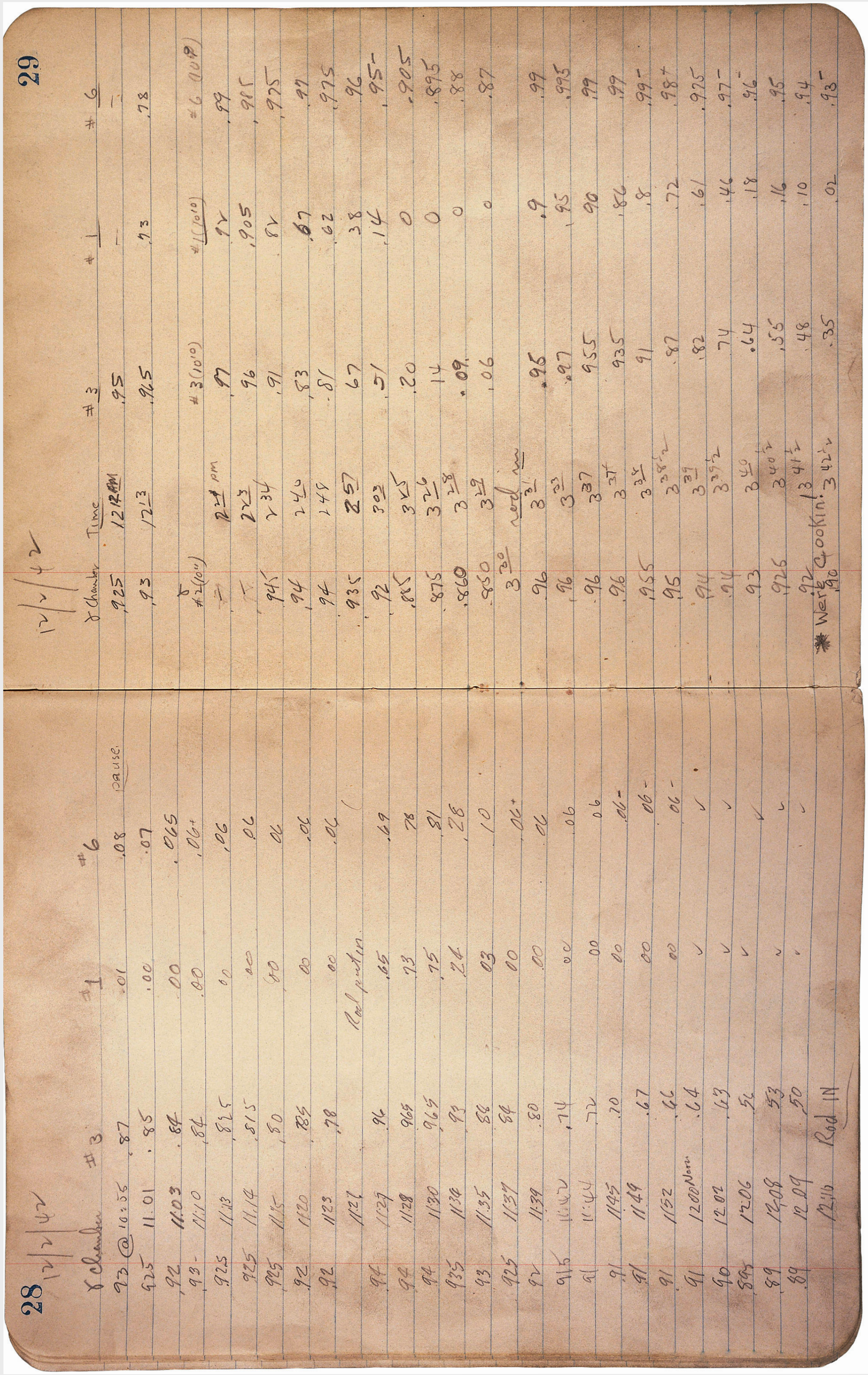
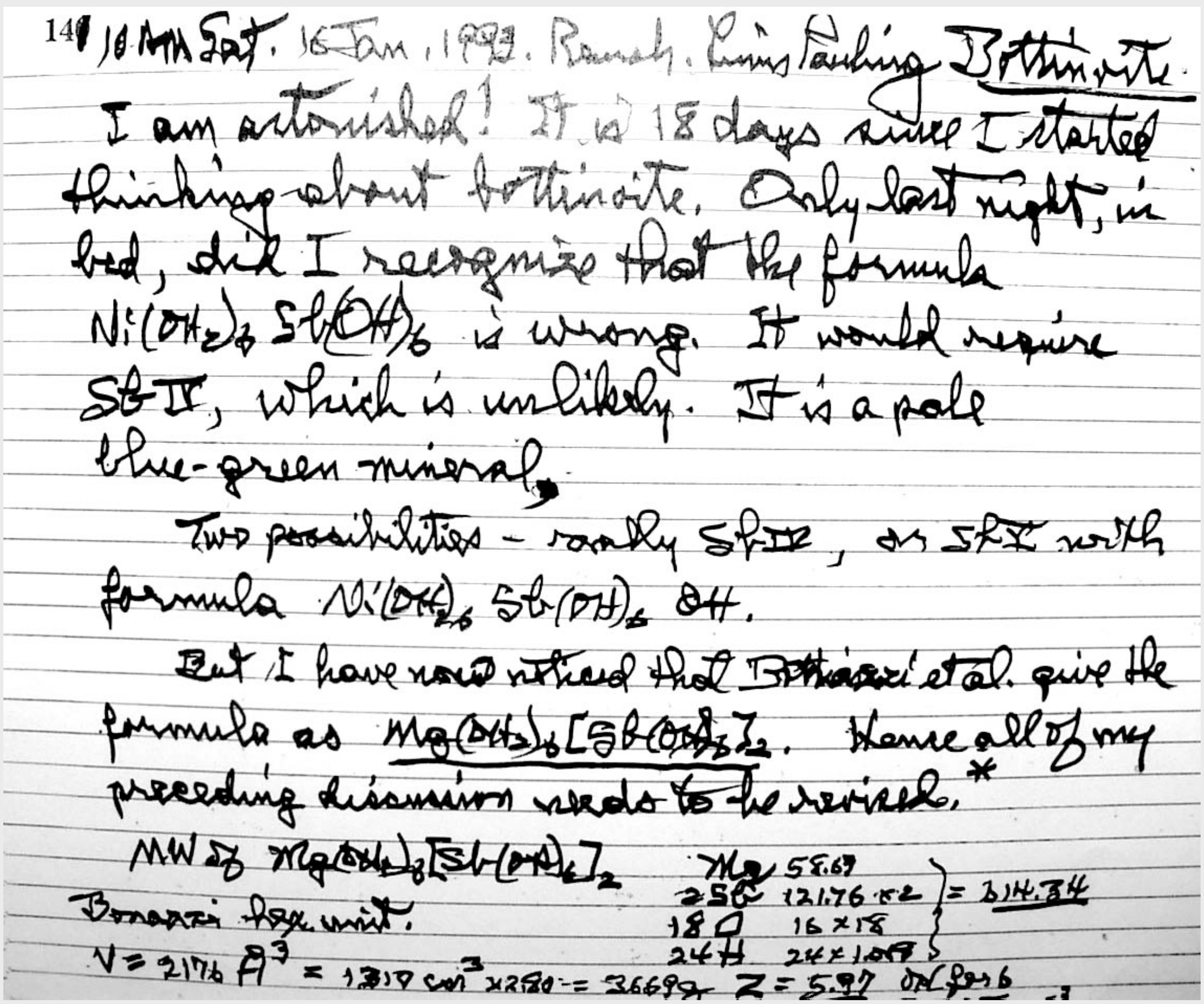


Fig. 4: Manhattan Project Notebook



14 10 AM Sat. 16 Jan. 1993. Ranch. Linus Pauling Bottinoite

I am astonished! It is 18 days since I started thinking about bottinoite. Only last night, in bed, did I recognize that the formula $Ni(OH_2)_6\,Sb(OH)_6$ is wrong. It would require SbIV, which is unlikely. It is a pale blue-green mineral.

Two possibilities – really SbIII, or SbV with formula $Ni(OH_2)_6\,Sb(OH)_6\,OH$.

But I have now noticed that Bonazzi et al. give the formula as $Mg(OH_2)_6[Sb(OH)_6]_2$. Hence all of my preceding discussion needs to be revised.*

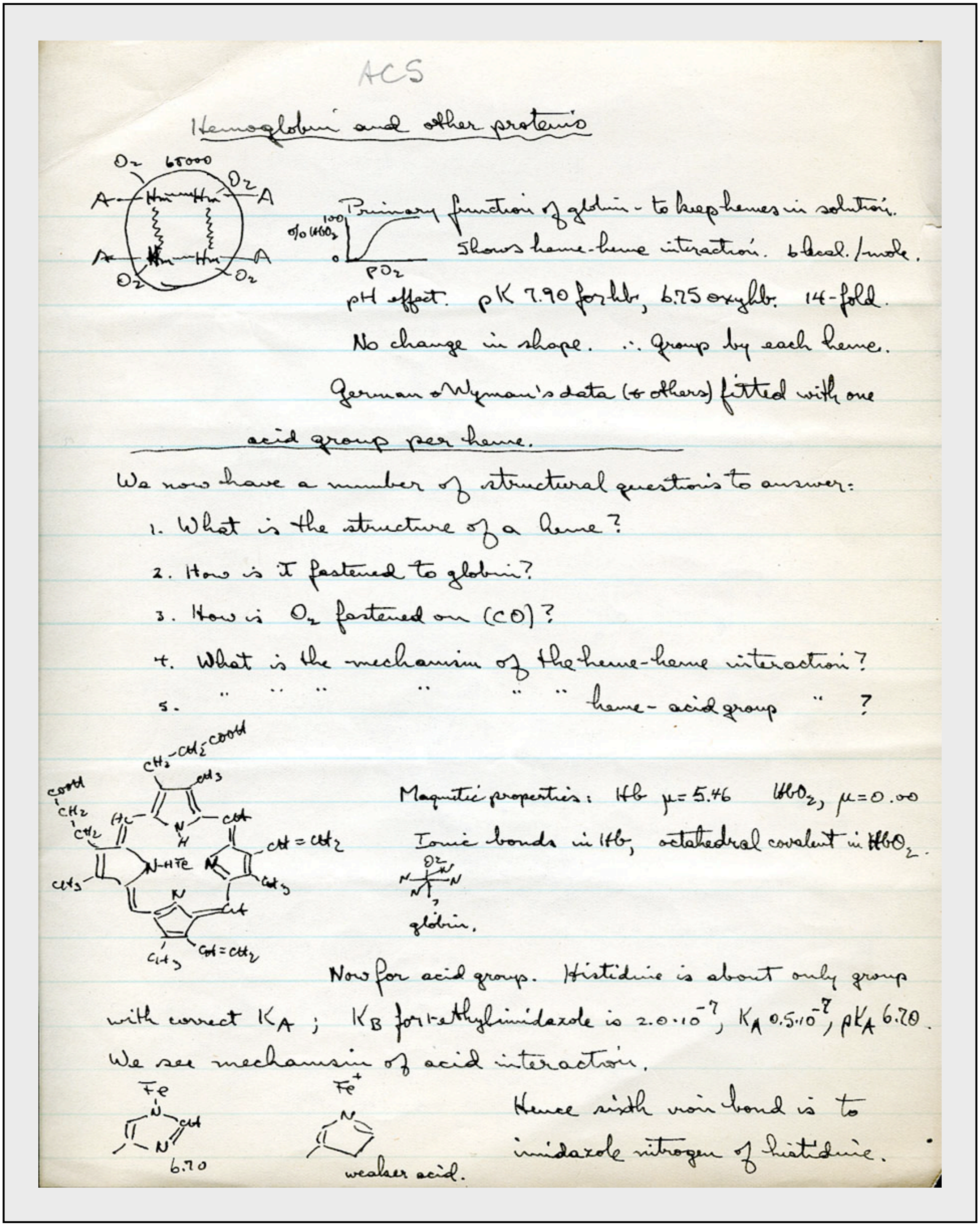
MW of $Mg(OH_2)_6[Sb(OH)_6]_2$

Mg 58.69
2 Sb 121.76 × 2
18 O 16 × 18
24 H 24 × 1.008
} = 314.34

Bonazzi hex. unit.

$V = 2176\ Å^3 = 1.317\ cm^3 \times 2.80 = 3.669\,g$ Z = 5.97 ok for 6

Fig. 5: Linus Pauling (on the crystal structure of bottinoite)



ACS

Hemoglobin and other proteins

O_2 65000

Primary function of globin – to keep hemes in solution.

% HbO_2 100, 0; pO_2

Shows heme-heme interaction. 6 kcal./mole.

pH effect. pK 7.90 for Hb, 6.75 oxyHb. 14-fold.

No change in shape. ∴ group by each heme.

German & Wyman's data (& others) fitted with one acid group per heme.

We now have a number of structural questions to answer:

1. What is the structure of a heme?
2. How is it fastened to globin?
3. How is O_2 fastened on (CO)?
4. What is the mechanism of the heme-heme interaction?
5. " " " " " " heme-acid group " ?

Magnetic properties: Hb $\mu = 5.46$ HbO_2, $\mu = 0.00$

Ionic bonds in Hb, octahedral covalent in HbO_2.

globin.

Now for acid group. Histidine is about only group with correct K_A; K_B for 1-ethylimidazole is $2.0 \cdot 10^{-7}$, K_A $0.5 \cdot 10^{-7}$, pK_A 6.70.

We see mechanism of acid interaction.

6.70 weaker acid.

Hence sixth iron bond is to imidazole nitrogen of histidine.

Fig. 6: Linus Pauling (on the structure of hemoglobin)