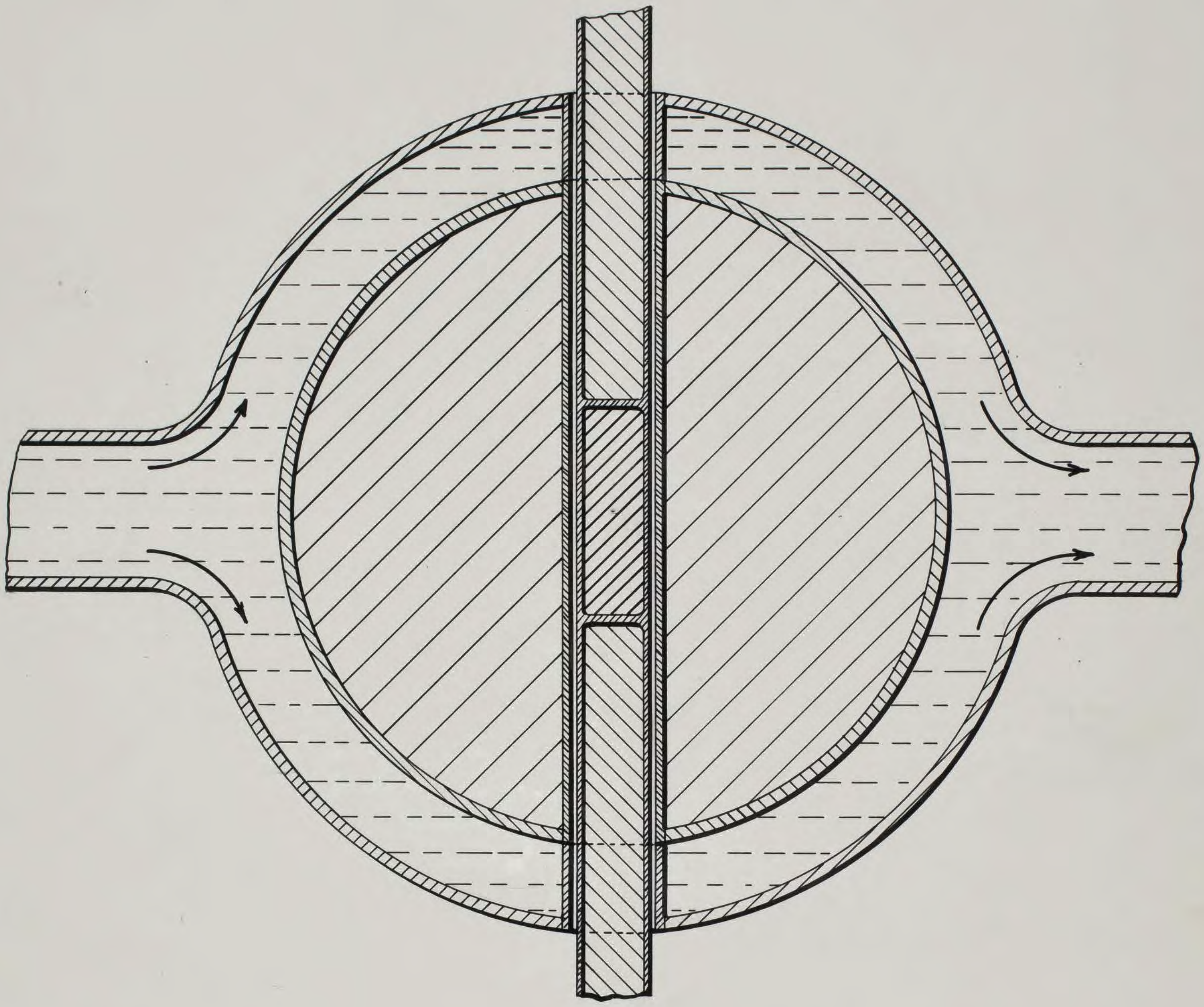
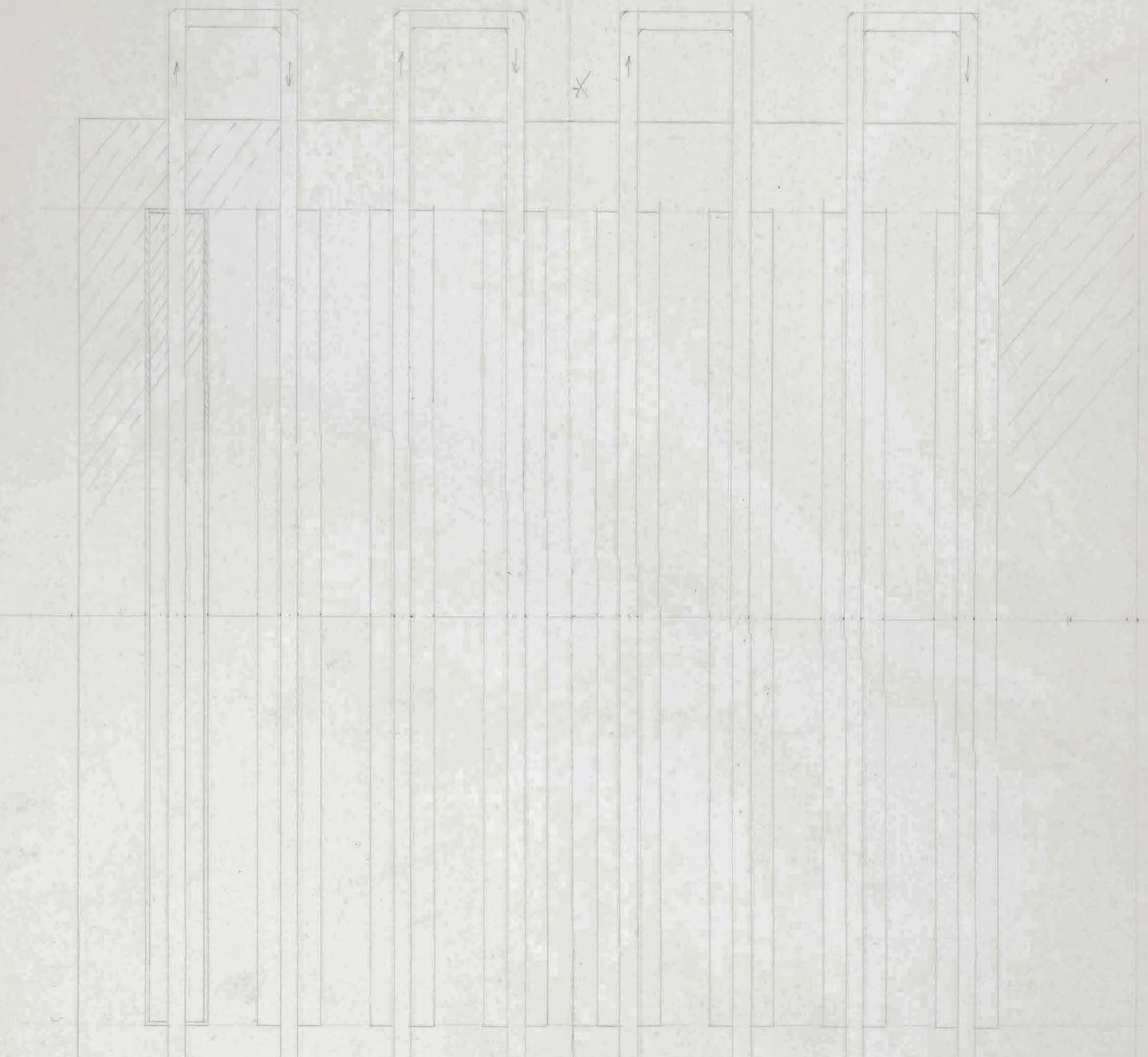


INVENTOR.

BY

Fig 7



INVENTOR.

BY

INVENTOR.

BY

Fig 5

Fig 6

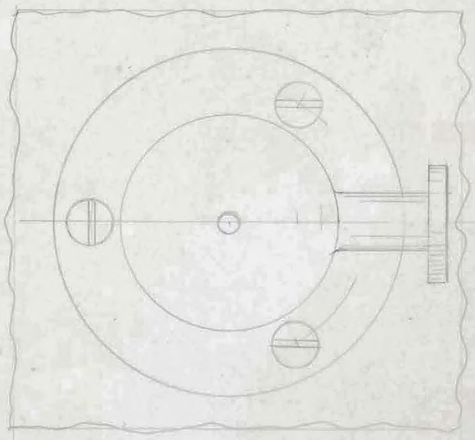


Fig 6

INVENTOR.

BY

Insert after first paragraph into paper "Nuclear chain reaction in a system composed of uranium, beryllium and carbon".

Both from the point of view of ~~xxxk~~ keeping the amount of beryllium which is needed small and of keeping the fraction of the neutrons which is absorbed by uranium at resonance with leading to fission at a minimum, it is of interest to consider the case of a ~~graphit~~ lattice of uranium spheres embedded in graphite, and in particular to consider the case of uranium spheres having a radius of about 3 cm. Using the formulae derived for such a lattice

Profesor D

Professor D P. Mitchell
Carnegie Institute of Terrestrial Magnetism,
Broad Branch Road N. W.,
Washington, D. C.

The purpose of the present paper is to show ~~that~~ how a chain reaction can be achieved by using an element like carbon for slowing down the neutrons in certain particular systems composed of carbon and uranium. The calculations in the present paper can be applied equally well to an element other than carbon provided that the range of thermal neutrons in a medium composed of this element is large compared to the range of the resonance neutrons.

For a number of practical reasons it would be preferable to use carbon in the form of graphite rather than hydrogen in the form of water for the purposes of a chain reaction. The capture cross-section of carbon for thermal neutrons is small. An upper limit of has been reported by Frisch, Halban, and Koch, but this upper limit is not sufficiently low to allow us at present to conclude that a chain reaction could be maintained in homogeneous mixtures of uranium and carbon. For neutrons it takes about 6.5 collisions with carbon atoms to reduce their energy by a factor of e. Thus a neutron which is being slowed down by carbon stays for a long time within the resonance absorption region of uranium. Consequently, very low uranium concentrations would have to be used in order to avoid that a large fraction of the fast neutrons emitted by uranium be absorbed by uranium at resonance. At such very low uranium concentrations, on the other hand, the fraction of the thermal neutrons which is absorbed by carbon might perhaps be too large to permit a chain reaction.

In the present paper we consider a system in which a large number of fairly large spheres of uranium which are practically black for resonance neutrons of uranium in an energy interval stretching from perhaps 2 to 20 volts are embedded in carbon. It will be shown that the ratio of the number of thermal neutrons and the number of resonance neutrons absorbed by the uranium can be made so small in such a system that we may expect a chain reaction to become a reality.

Figure 1 shows the cross-section of a large graphite sphere and a number of small uranium spheres embedded in the graphite. These uranium spheres form a close-packed cubic or hexagonal lattice in the graphite and one Netzebene of the lattice is visible in the drawing. Figure 2 a and b shows a single uranium sphere 1 which has a slit 2 going through its middle. A flat tube 3 containing a circular disc 4 which is made of an element which strongly absorbs thermal neutrons can glide up and down in the slit 2. The uranium sphere is encased as shown in figure 2 a and b and liquid bismuth or a liquid lead bismuth alloy flows through tube 5 encircles the uranium sphere and leaves it through tube 6.

Figure 3 shows part of the system adapted to cool the uranium spheres by liquid bismuth or bismuth alloy. The liquid bismuth is pressed into tube 10, and several rows of uranium spheres as shown in Figure 3, are connected in parallel. The liquid bismuth which is warmed up by the heat transfered from the uranium spheres is collected in tube 11. Figure 4 shows in what way the stabilizing strips or tubes 20, 21, etc. are moved up and down by a number of motors 22, 23, etc. These motors are switched in and reversed by the switches 24, 25, etc. which are controlled by the amplifiers 26, 27 etc. and these amplifiers in their turn are controlled by the ionization chambers 28, 29, etc. in such a manner that when the neutron irradiation emanating from the chain reaction leads to an increased ionization the corresponding in any of these ionization chambers the corresponding motor moves the tubes 20, 21, etc. upward and thereby moves the circular discs 4 away from the centers of the uranium spheres.

CLAIMS

1. A method for producing power consisting in maintaining a chain reaction in a system composed of uranium and carbon.

2. A method according to Claim 1. in which small bodies of uranium or a uranium compound are embedded in a large mass of carbon.

3. A method according to Claim 2 in which small spheres containing uranium are embedded in a large mass of carbon.

4. A method according to Claim 3 in which small spheres of uranium metal are embedded in a large mass of carbon.

5. A method according to claims 1 to 4 in which liquid bismuth flows through the system composed of uranium and carbon and carries away the heat produced in the chain reaction.

6. A method according to Claims 2 to 4 in which liquid bismuth or a liquid alloy of bismuth and lead surrounds the uranium bodies embedded in carbon.

7. A method according to Claims 2 to 6 in which the chain reaction is stabilized by having a thermal neutron absorber within the uranium bodies or near the surface of the uranium bodies, and means to control the position of these thermal neutron absorbers in such a way that the absorber is moved away from the center of the uranium body if the intensity of the chain reaction increases

8. A method according to Claim 7 the position of the thermal neutron absorbers is controlled by the effect of the irradiation emitted in the chain reaction on an ionization chamber which acts on a switch that controls a motor which moves the thermal neutron absorber.

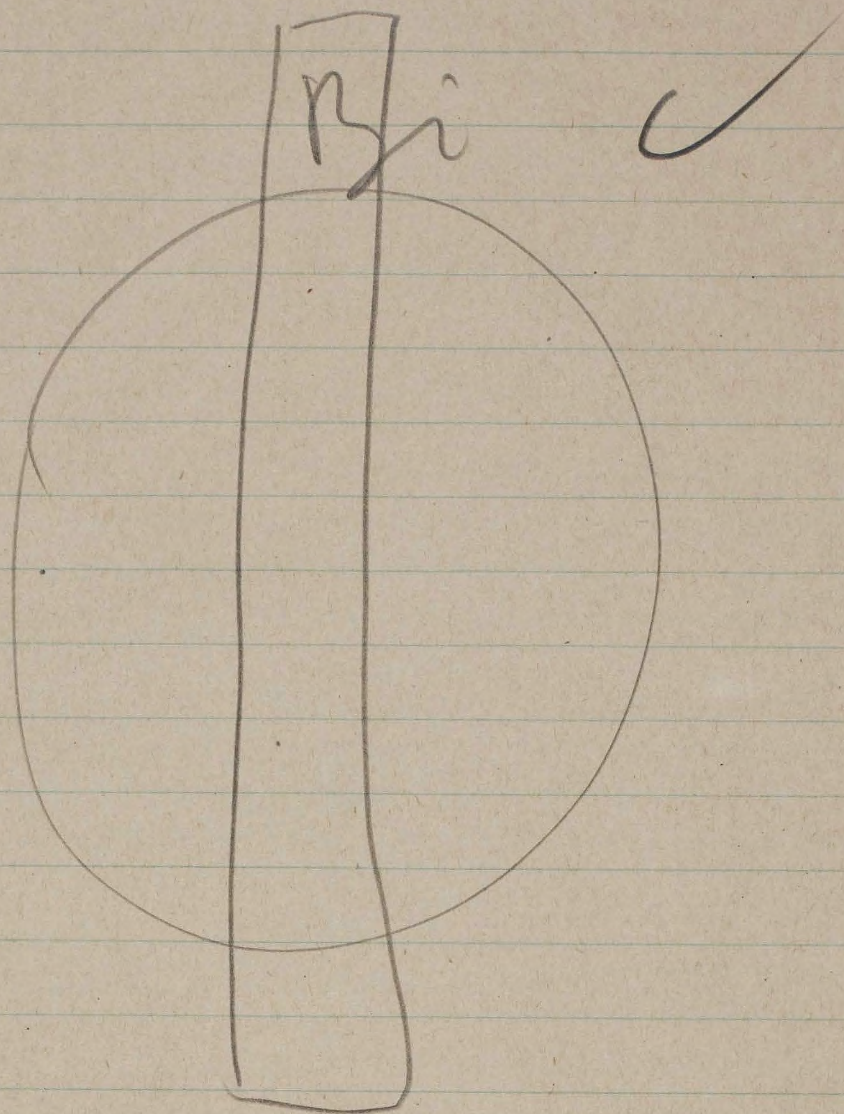
If flat sheets of uranium or uranium oxide are embedded in carbon a large fraction of the neutrons will be absorbed by the uranium at resonance and conditions will not be favorable for a chain reaction. If, however, a large number of bodies of uranium oxide or uranium metal are embedded in carbon for which at least 2 of the dimensions (like ~~in~~ it is the case ~~of~~ for a long cylinder of small radius) are small compared to the range of the resonance neutrons in carbon we obtain more favorable conditions. Even more favorable conditions are obtained if all three dimensions of the uranium-containing body which is embedded in carbon are small as, like it is the case ~~for instance~~, a sphere of uranium metal ~~which has a radius~~ of about 5 to 8 cm. is ~~embedded in graphite of density 1.7~~ radius. A large number of such spheres ~~can~~ has to be used which may form a cubic or hexagonal lattice within a large sphere of graphite.

Having such bodies of uranium embedded in graphite rather than in a homogeneous mixture offers according to this invention the possibility of leading away and utilizing the heat liberated in the chain reaction in such a way that the system serving the purpose of heat transfer does not block the chain reaction by unduly increasing the neutron absorption within the uranium carbon system. If, for instance, a lattice of uranium metal spheres is embedded in carbon the thermal neutron density will be particularly low in the neighborhood of the uranium spheres in the carbon. Accordingly, a cooling liquid like liquid bismuth or a liquid bismuth alloy may be present in fairly large quantities in the close neighborhood of these uranium spheres without absorbing a large number of thermal neutrons. Since most of the heat is liberated within the uranium spheres this principle leads to an efficient method of leading away and utilizing the heat liberated in the chain reaction.

The fact that the thermal neutron density is small near the uranium spheres and even smaller within a slit inside the uranium spheres makes it possible according to this invention to control the chain reaction for the purpose of stabilizing it. If we have a thermal neutron absorber within or near the uranium sphere, i. e. at a point where the thermal neutron density is comparatively low and if we move this absorber further away from the center of the uranium sphere to a point where the thermal neutron density is comparatively high we can bring about a big change in the thermal neutron density by moving the thermal neutron absorber only a short distance. Since we thus have to move the controlling absorbing bodies only a short distance the movement can be achieved in a short time and we obtain an efficient method of control. This control can be made fully automatic. For the sake of safety a number of individual controlling units may be used. The position of these thermal neutron absorbers may be controlled by an electro motor which is switched in and reversed by a switch, this switch may be controlled by an ionization chamber which is exposed to the neutron irradiation emitted by the chain reaction. If the neutron irradiation increases the current passed by the ionization chamber increases and the motor is switched in such a way as to move the thermal neutron absorber away from the center of the uranium sphere. One motor can serve a number of uranium spheres but a number of individual units each of them controlled by a separate ionization chamber ought to be used for reasons of safety. The damping of the motors should be sufficient to insure an aperiodic functioning.

Seite 2, § 1, unveraendert.

According to this invention a nuclear chain reaction can be maintained in a mixture of carbon and uranium, or in a body which is composed of alternating layers of uranium and carbon. The uranium can be present as metallic uranium or as uranium oxide, or in some other suitable form, and the carbon can be present as carbon graphite or in some other suitable form. The ratio of the uranium atoms to carbon atoms in the mixture must exceed at least 16 to 1 and may be as high as   to 1. The lowest permissible value for this ratio is determined by the consideration that the neutrons emitted by uranium under the action of thermal neutrons must be slowed down by carbon to thermal energies before they are captured at resonance by uranium, and this value is in excess of   . The highest value for this ratio is determined by the consideration that thermal neutrons must be captured in the mixture by uranium before they escape from the surface of the body in which the ~~xxxxx~~ chain reaction is maintained. The critical dimensions of such a body are determined by the average displacement for slowing down the fast neutrons which are emitted by uranium. This displacement has a value in carbon of   and the critical radius is of the order of magnitude of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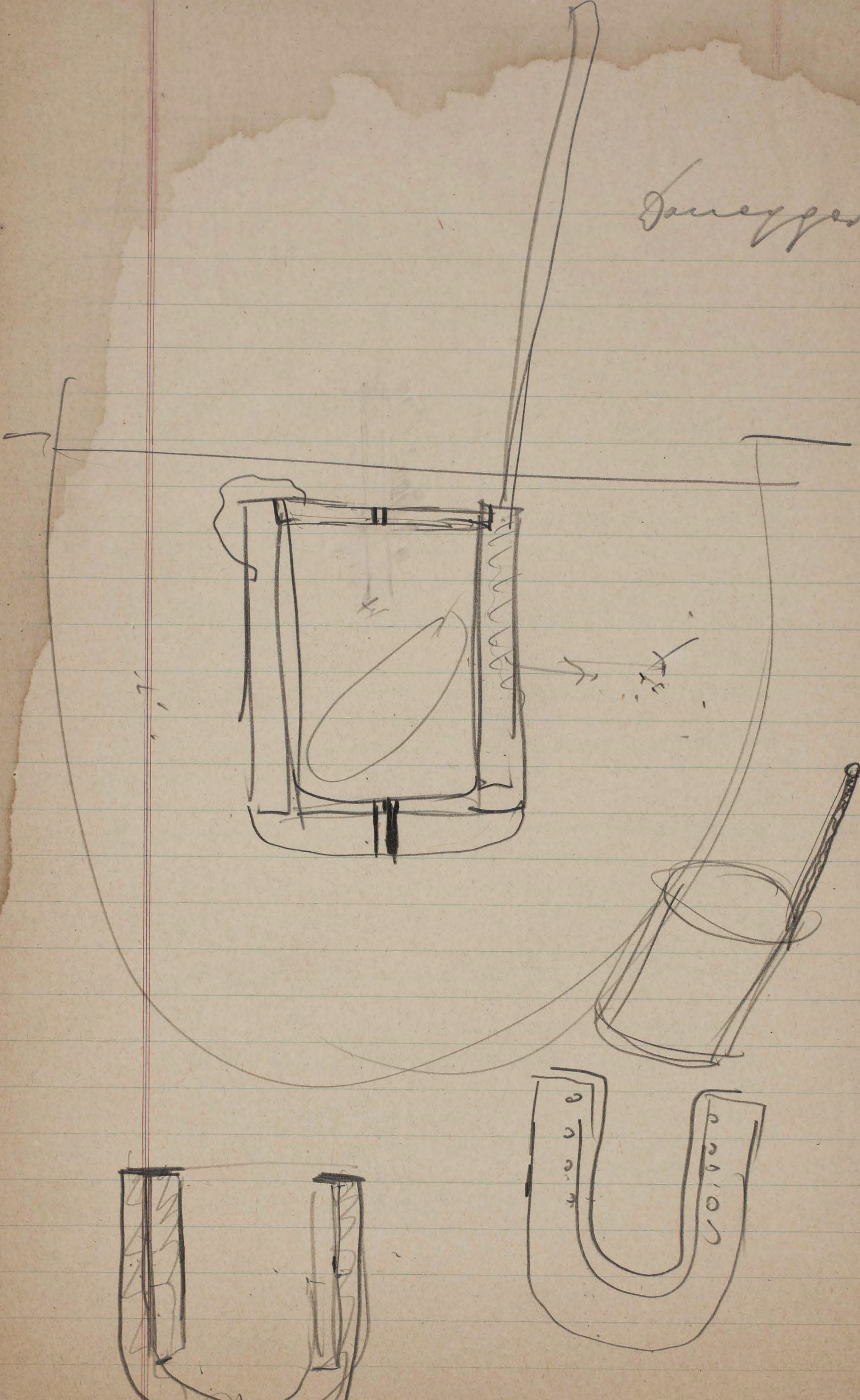

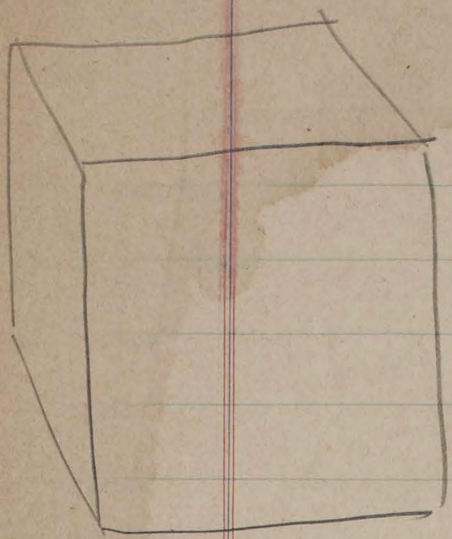

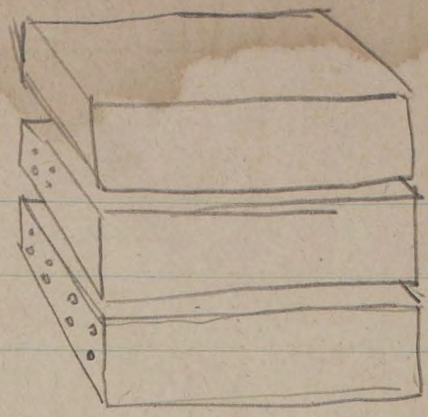

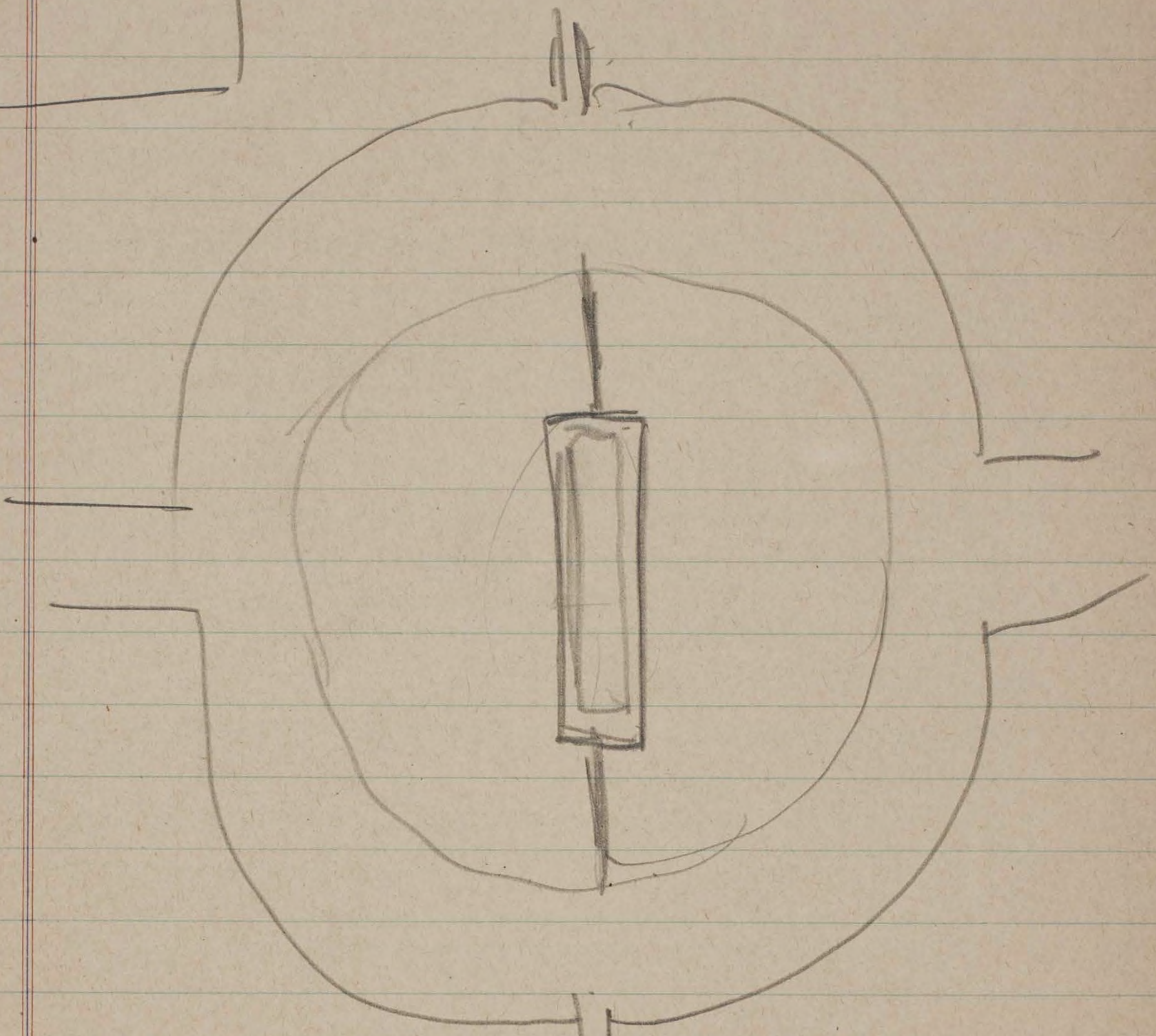

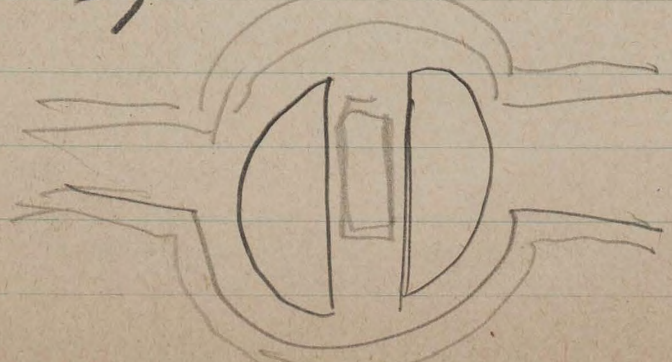

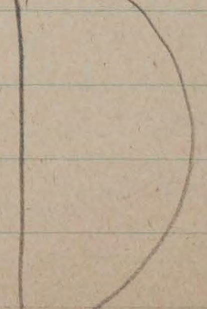

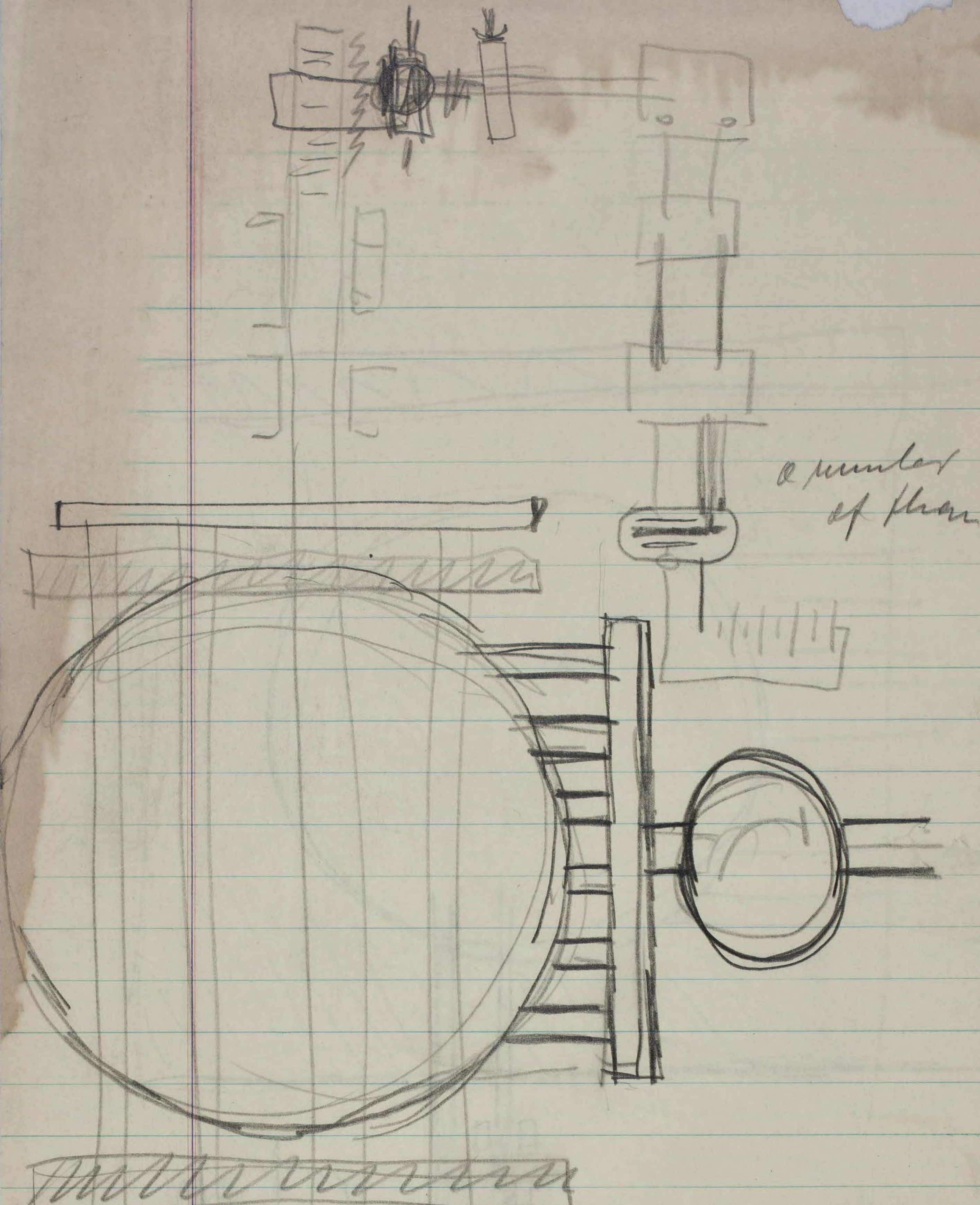
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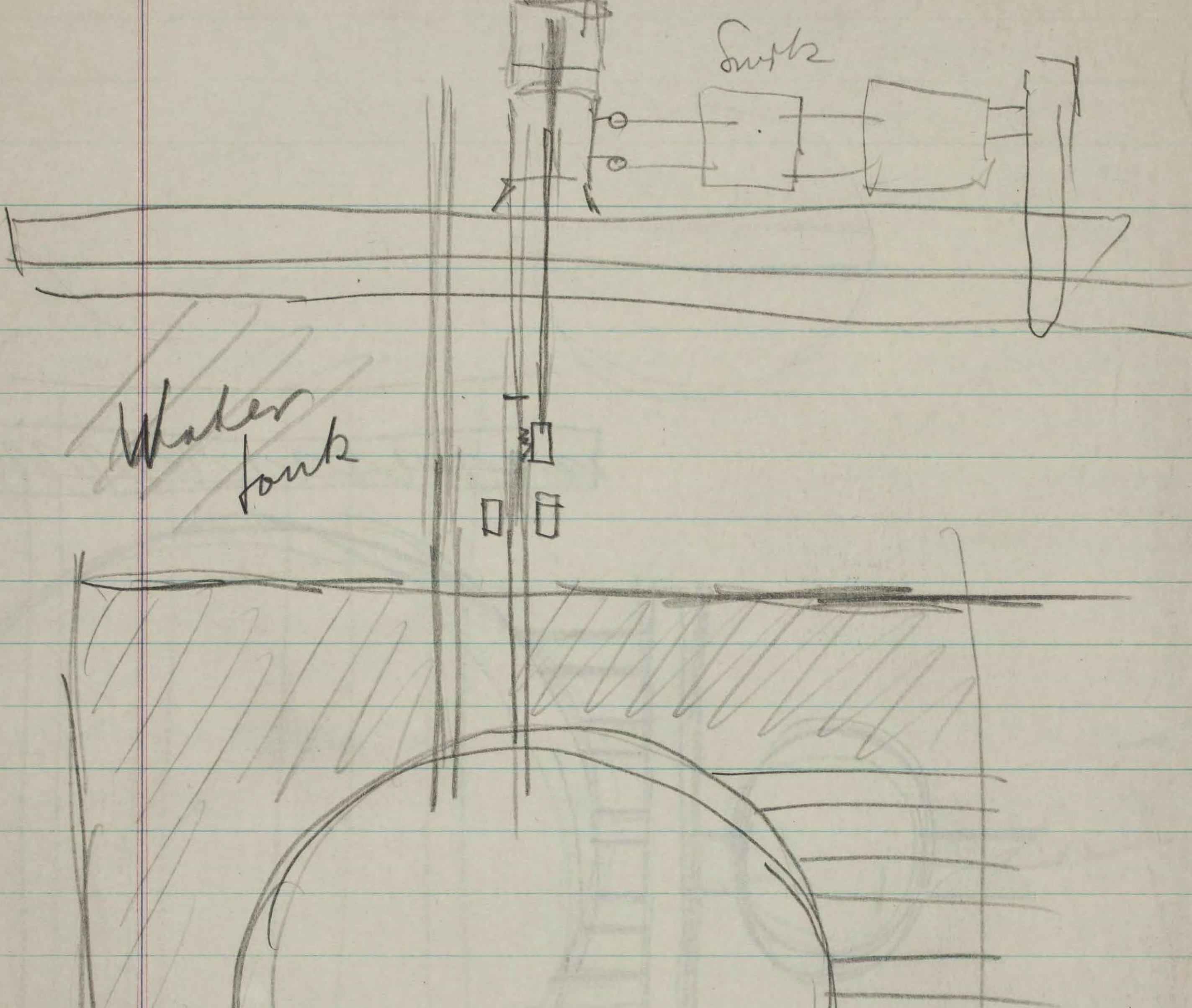
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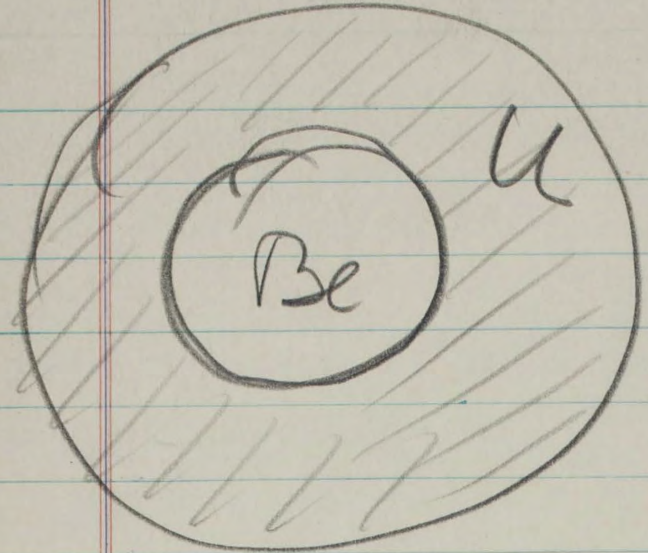

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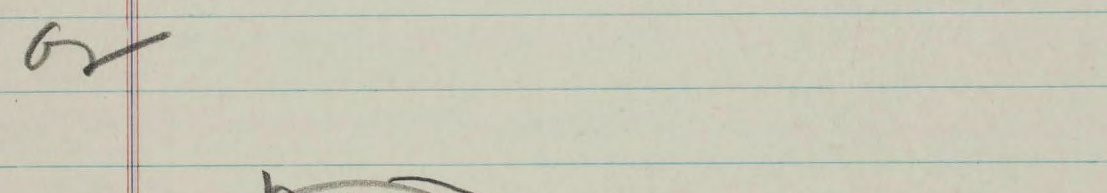

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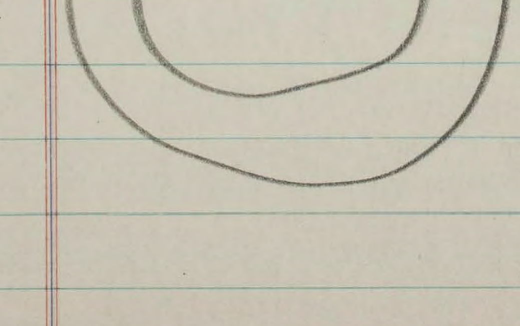

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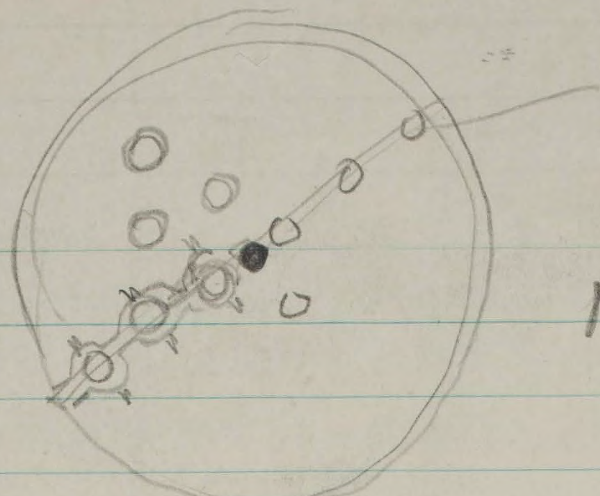

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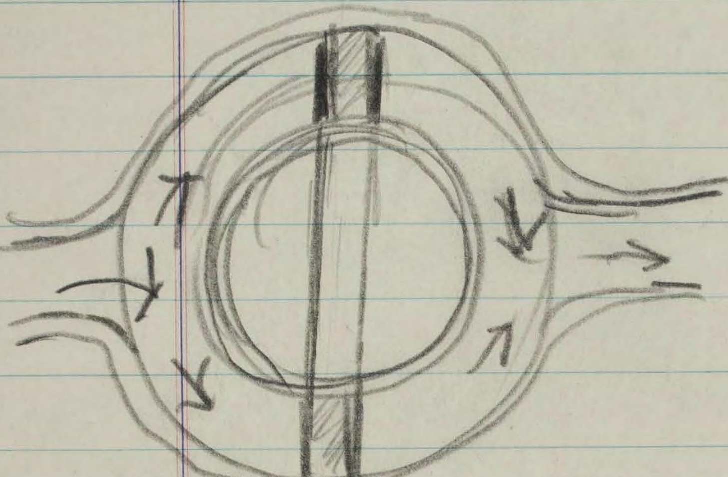
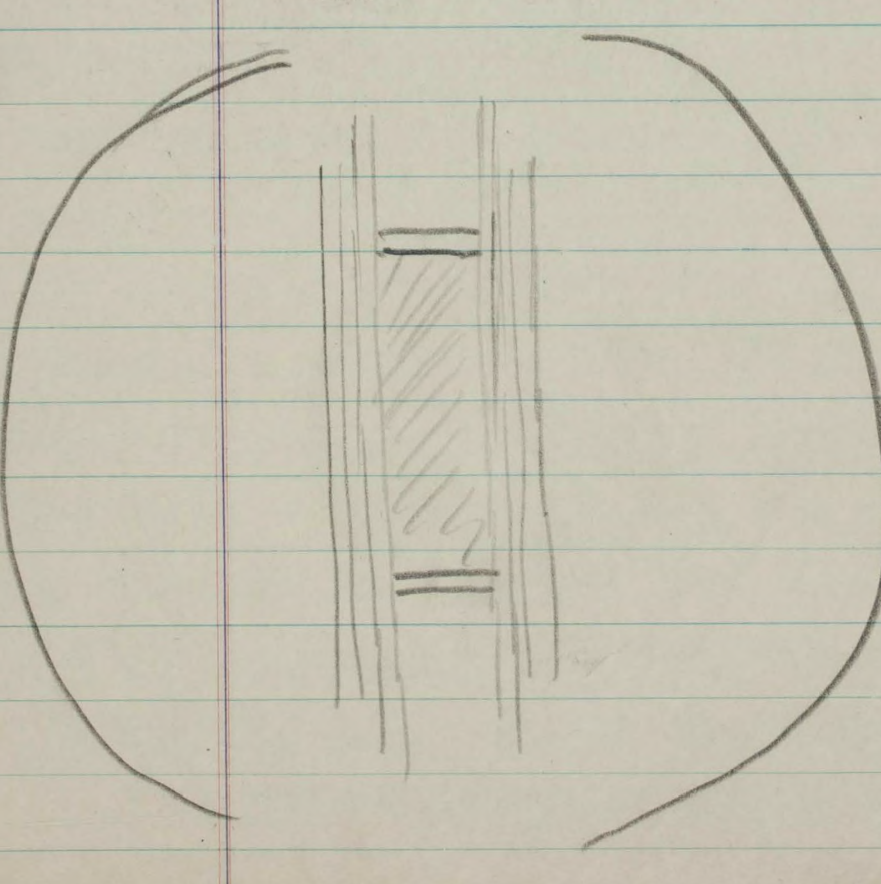
leave ring free
from circle

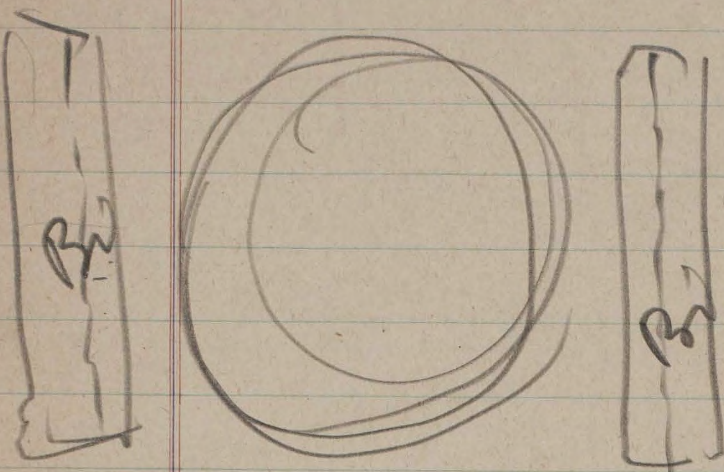


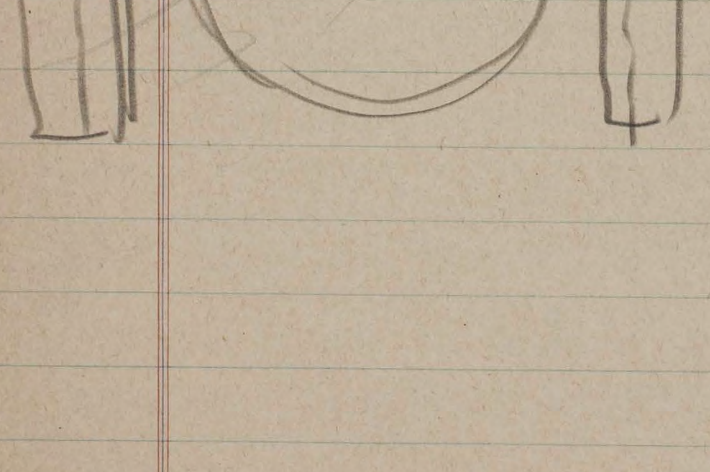


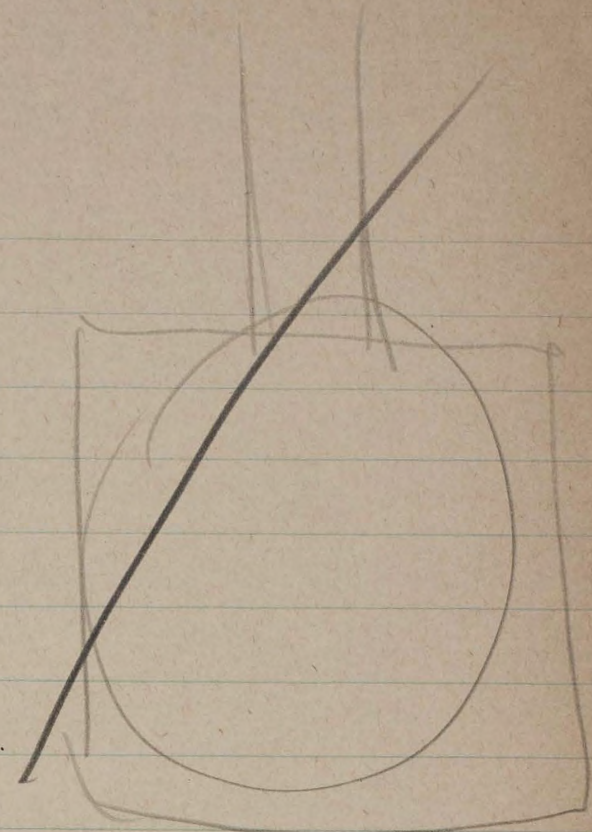
N_2 in Graphite

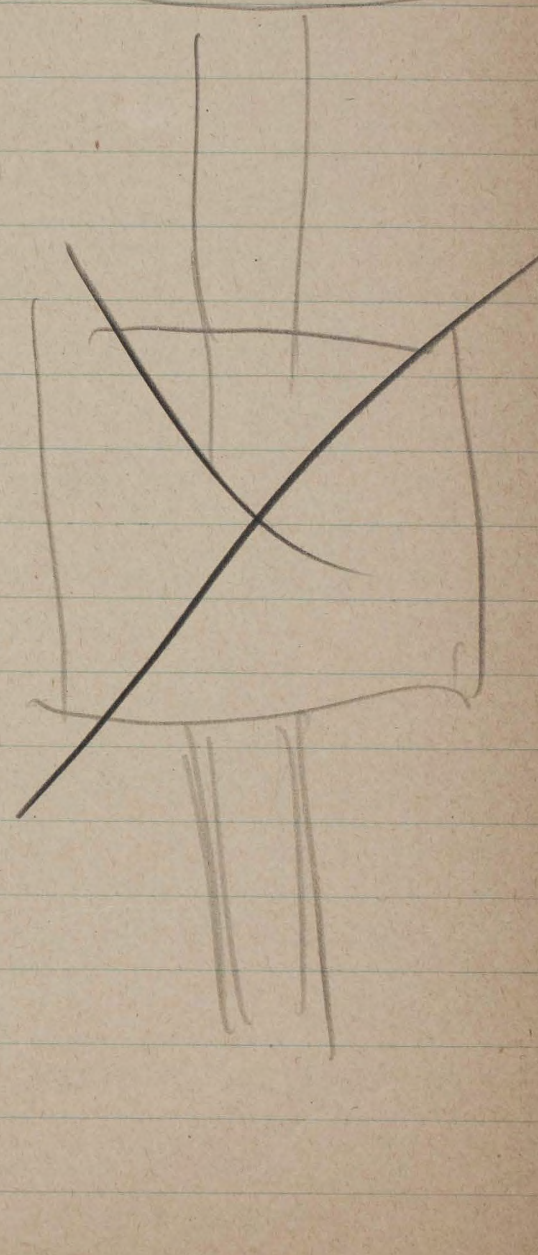
$4 \times \frac{1.3}{25}$ gr/liter N_2 as against $= \frac{1}{5}$ gm

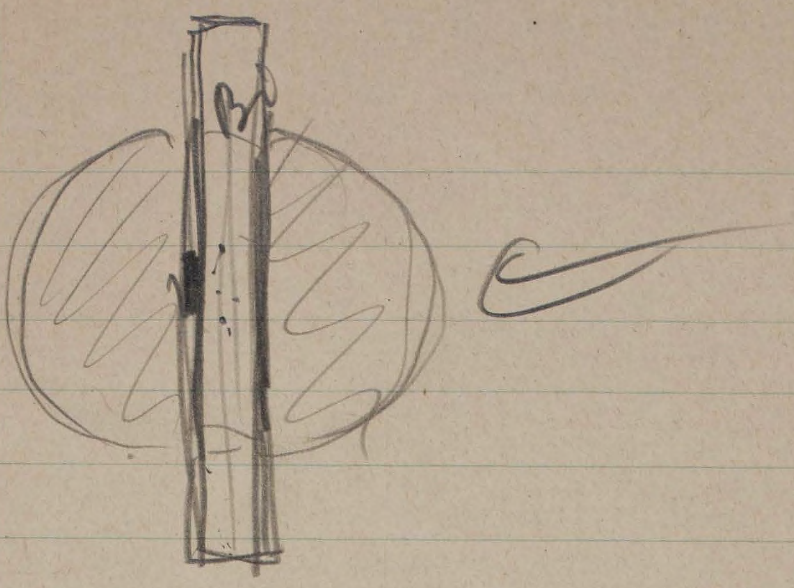
1,700 gm Carbon [N] = [C]

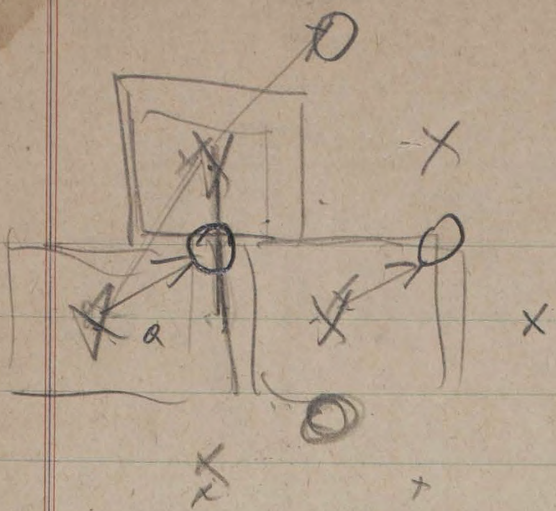


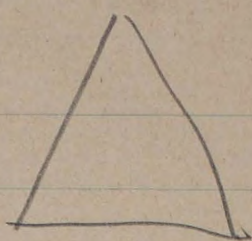


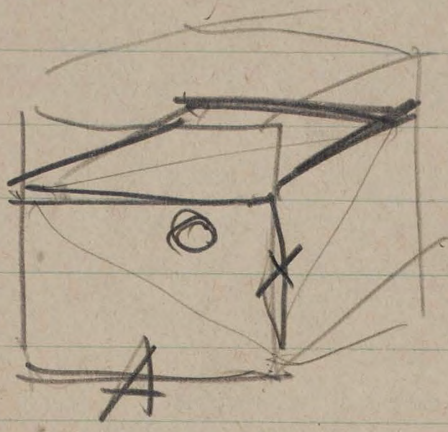










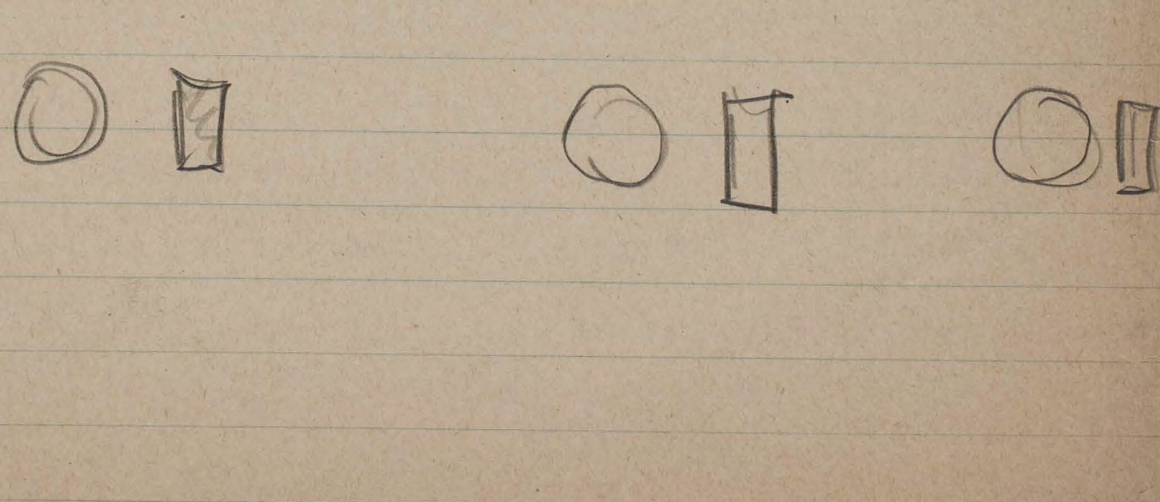


$(2a)^2 - a^2 = x^2$

$3a^2 = x^2$

$x = \sqrt{\frac{3}{4}} \cdot A$

close pack lattice ↑

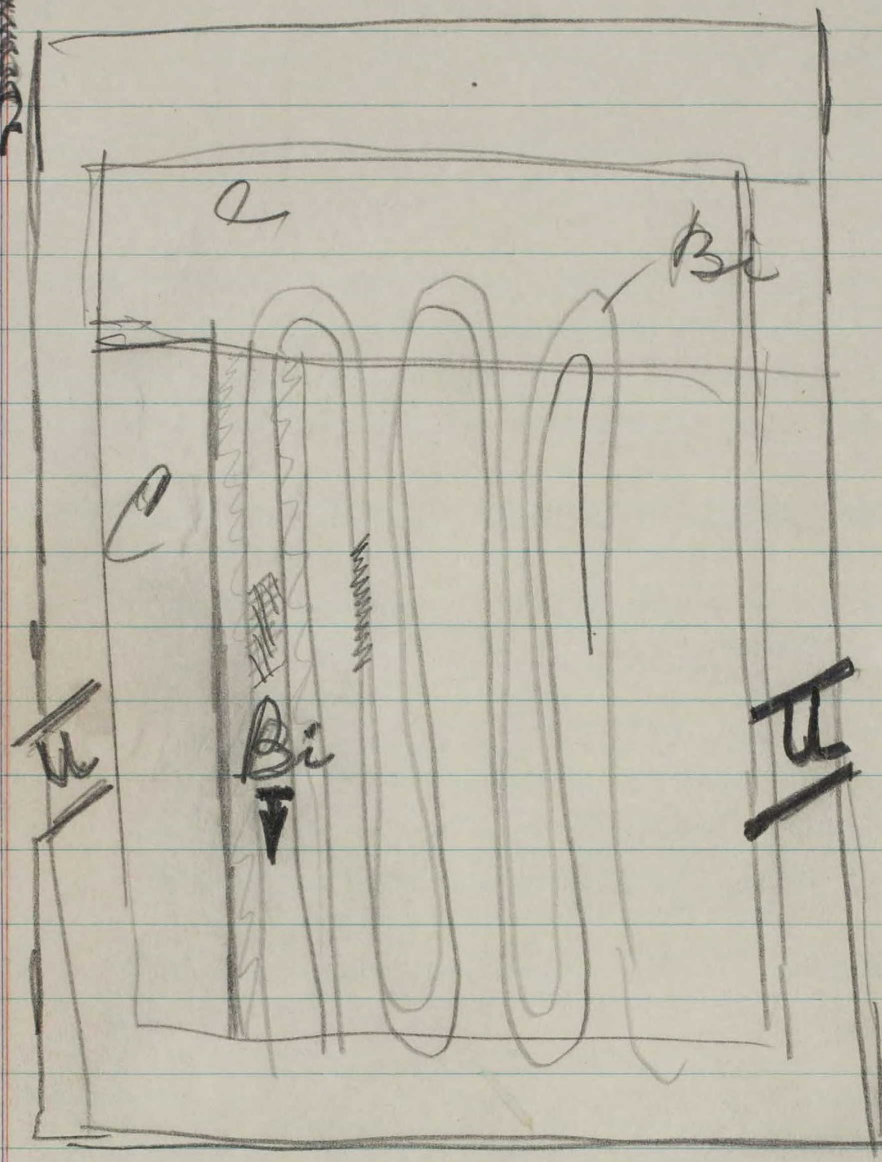


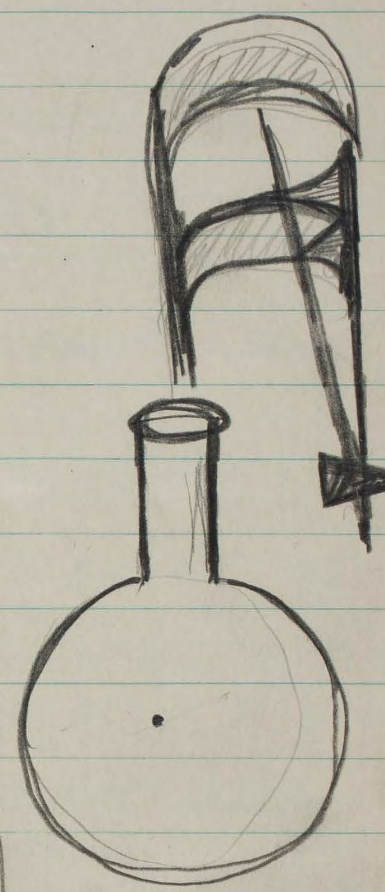
5

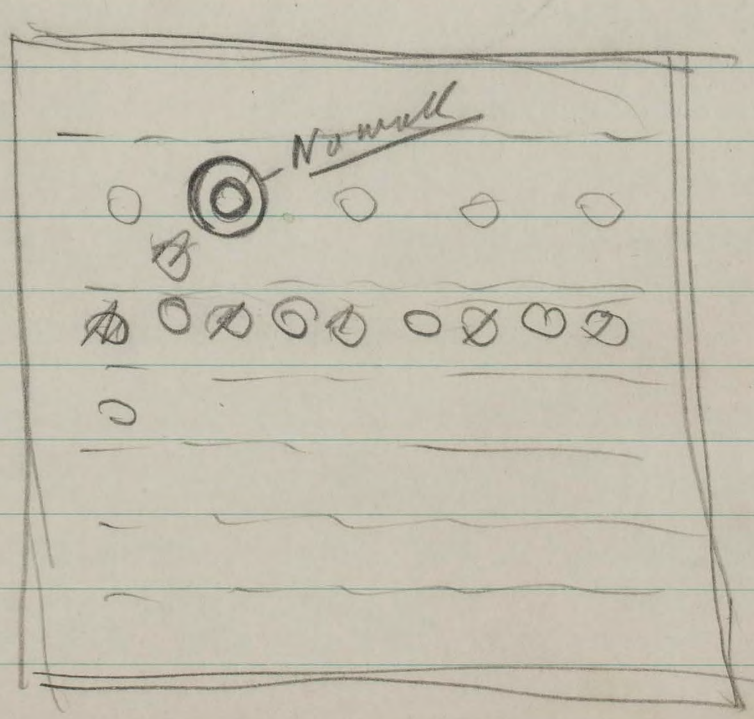
20

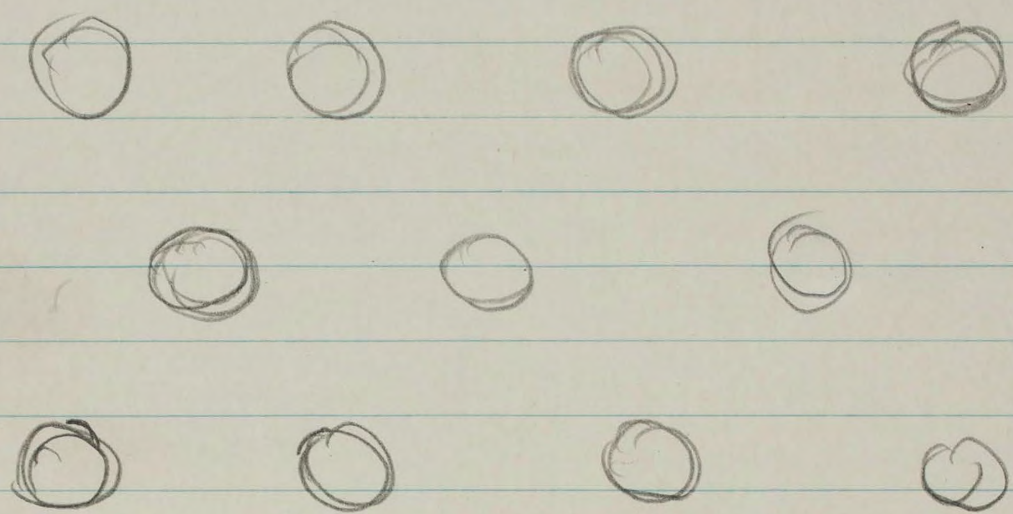
0.25

10 —③

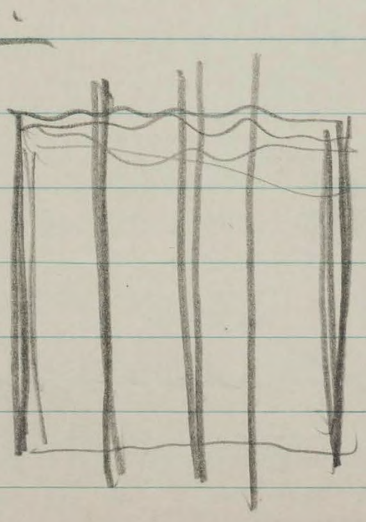








If metall is used oxidation
has to be prevented. Walls sand
carbon, carborundum, —
oxide in cylindrical arrange-
ment.



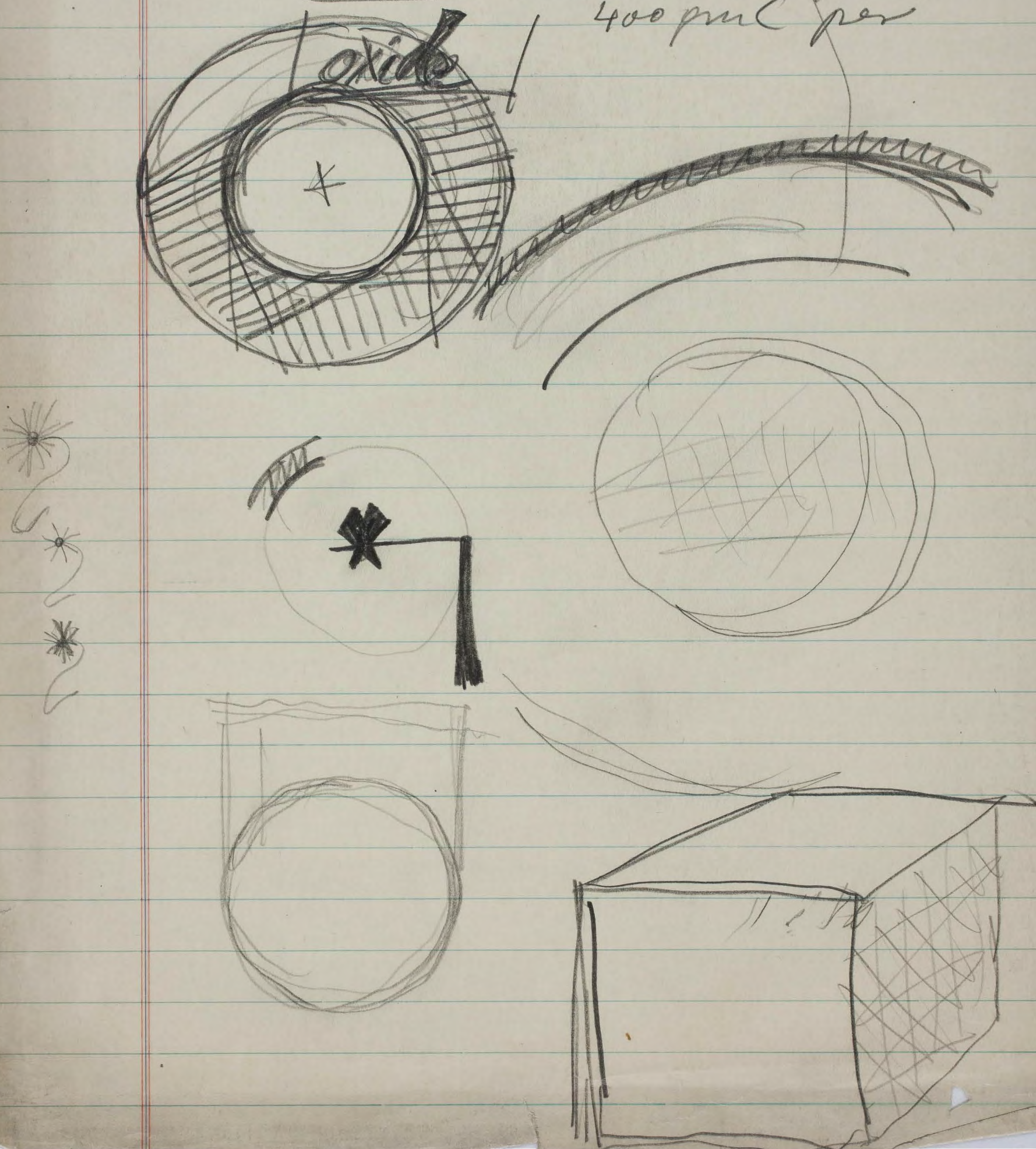
Air N_2 air

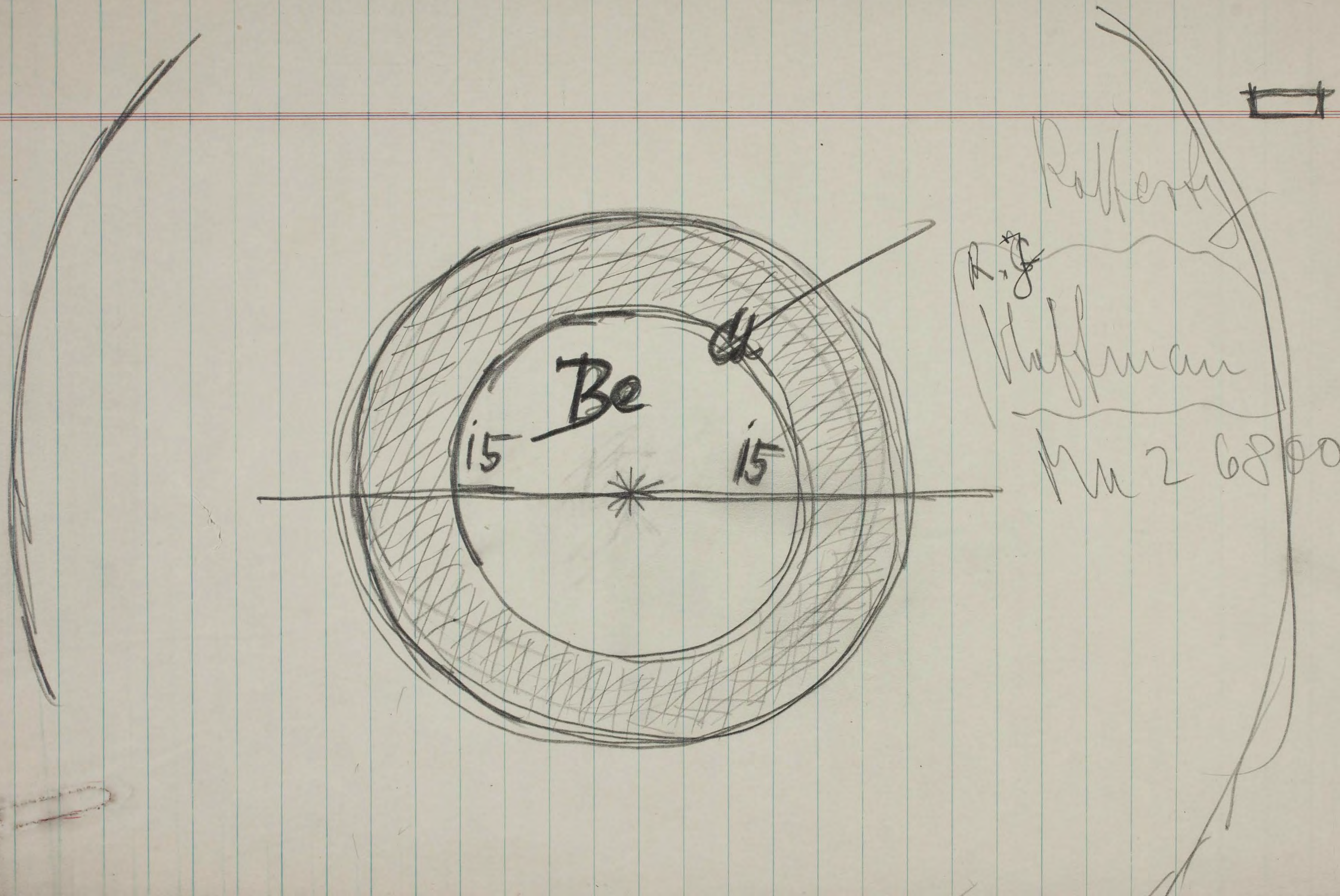
Graphite

1.7 2.1 0.4 gm C 3/4

lacking

400 gm C per

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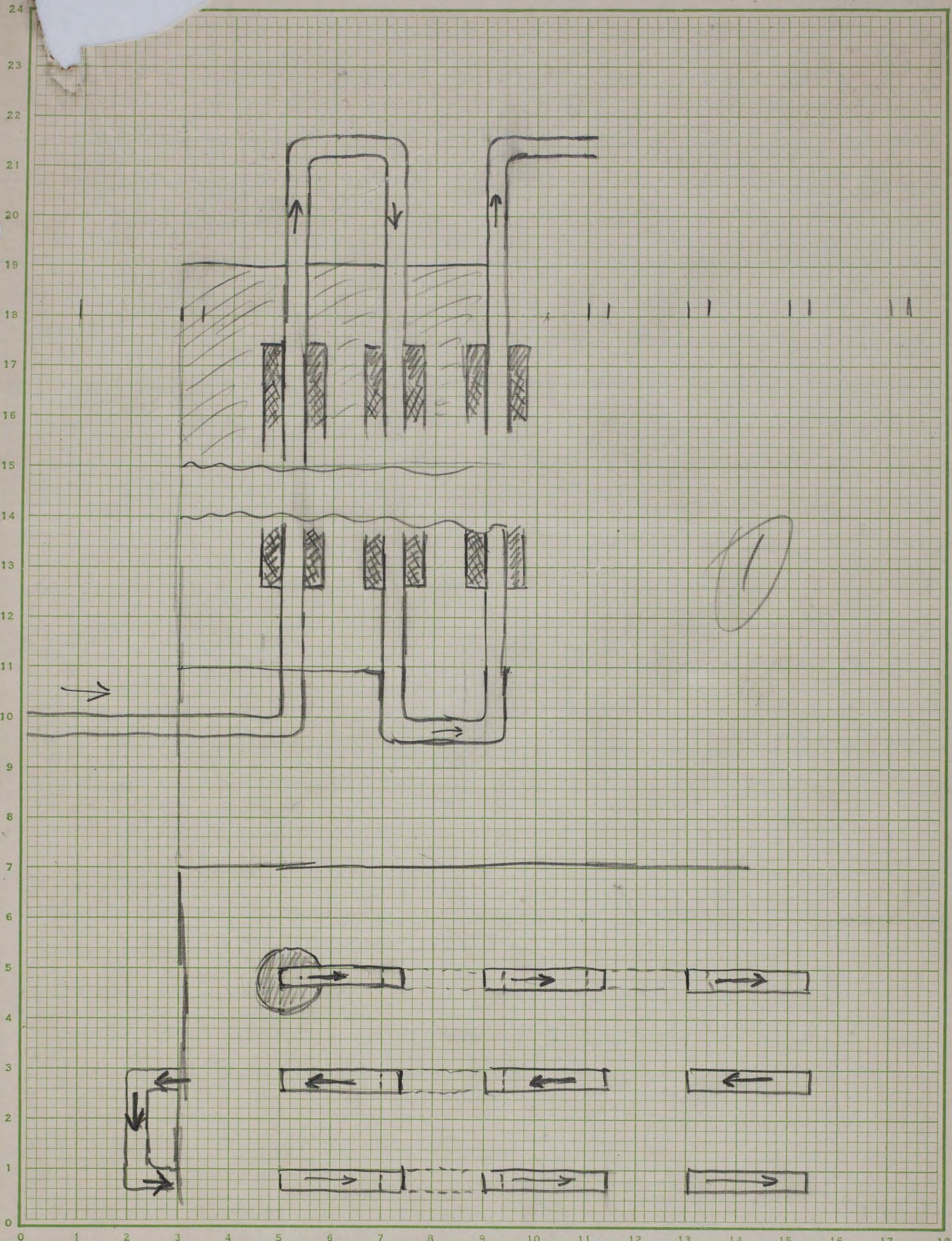

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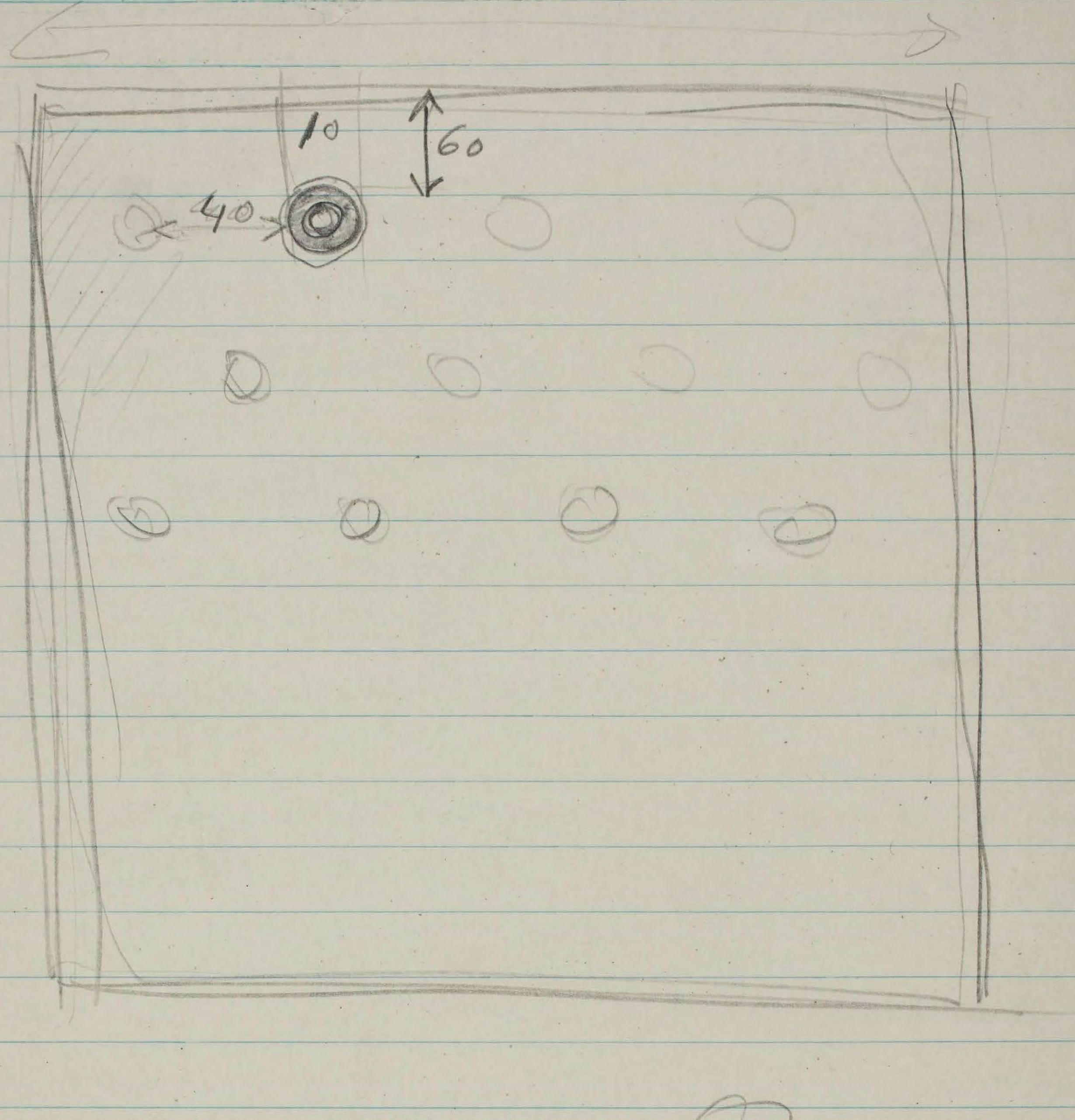
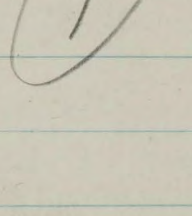
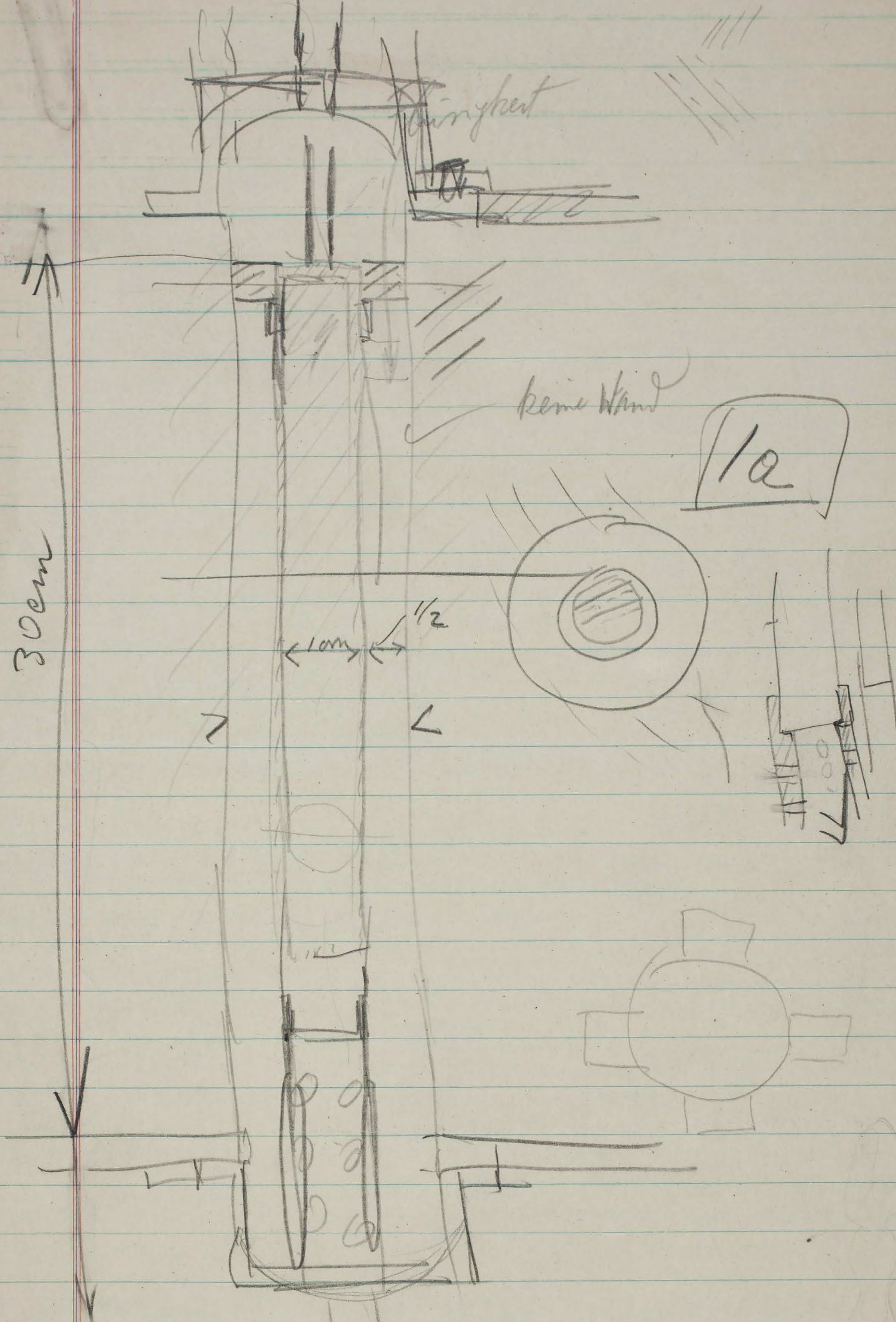


$l = b = h$





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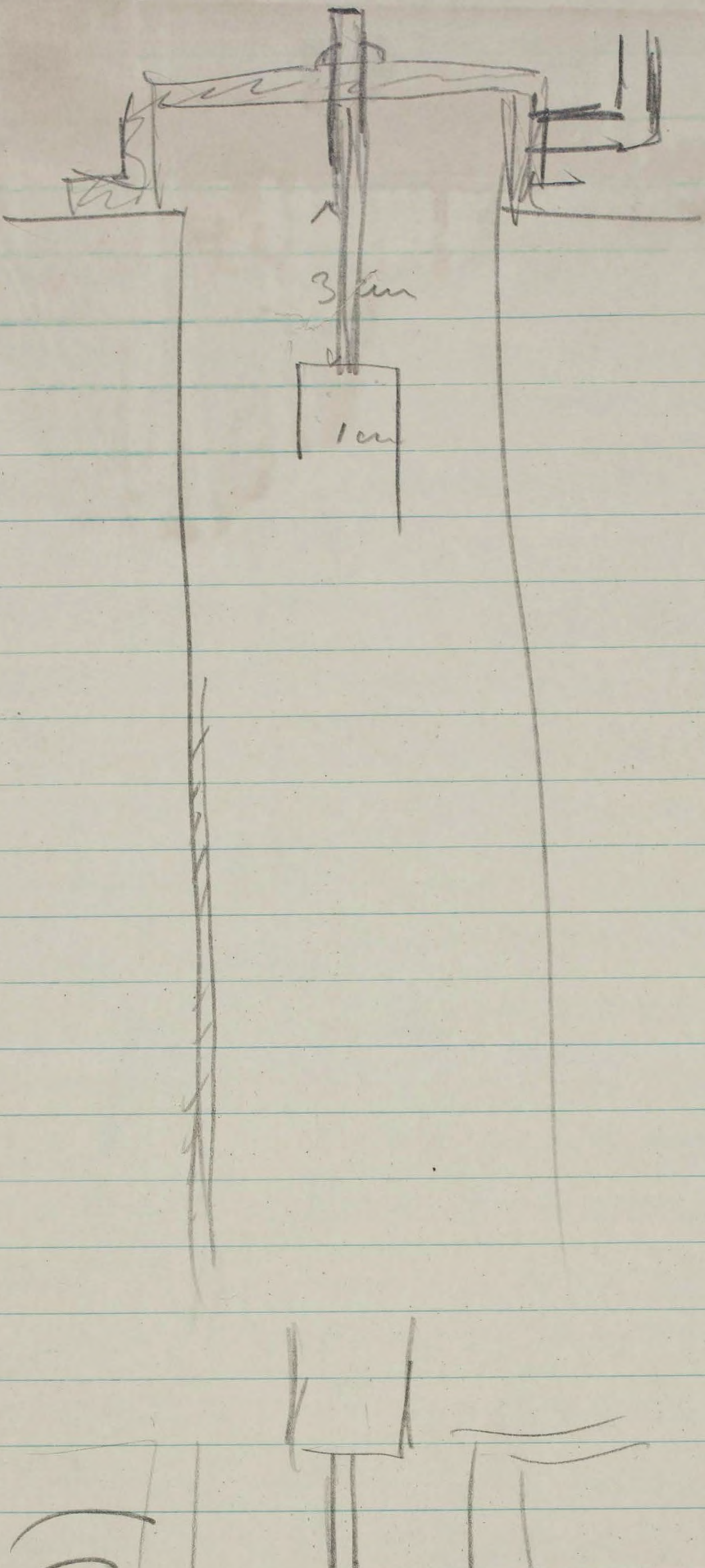

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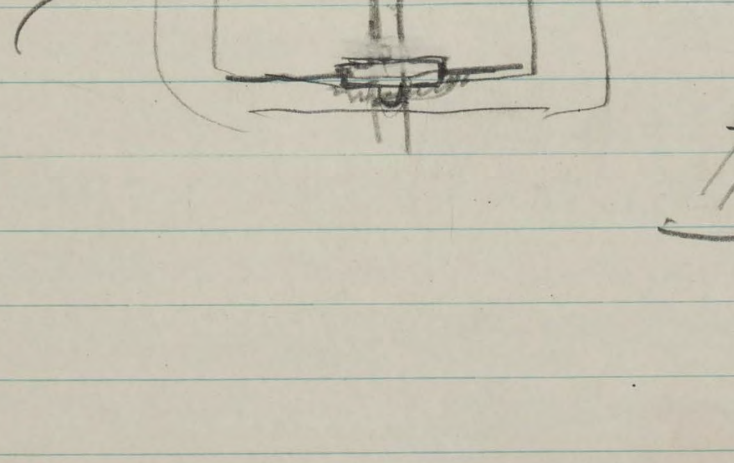
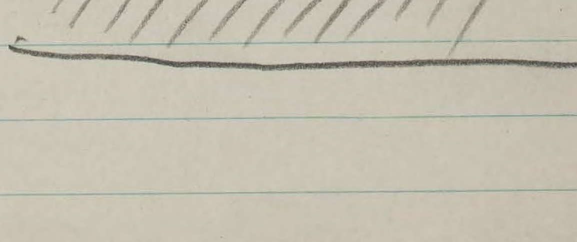




PATENT December 9, 1940

Method of Cooling.

1. No cooling liquid inside the graphite-uranium system.

2. Cooling by liquid bismuth, the bismuth surrounding the uranium spheres; the bismuth flowing in graphite channels and not in iron pipes.

3. Cooling by some cooling liquid, for instance a bismuth-lead compound containing 60% of bismuth, melting at 126°, flowing inside a uranium tube inside a uranium cylinder. This method can be used only if cylindrical bodies of uranium are embedded in graphite. In this arrangement liquid mercury could be used instead of liquid bismuth or bismuth alloys; also perhaps water. Note: melting point of bismuth 322°; melting point of lead 326°. A Pb-Sn alloy containing 70% Sn melts at 185°. There may be suitable Sn-Pb-Bi alloys. Boiling point of bismuth is at 1470°. Boiling point of lead is at 1613°.

Heating up.

If the cooling medium is used which becomes solid at room temperature it may be necessary to heat up the carbon-uranium system in order to start the machine. ~~Otherwise~~ Another reason for heating up may lie in the fact that the graphite used contains impurities which have an appreciable thermal absorption. In the case of an appreciable thermal absorption in the graphite, whether due to impurities of a certain kind or to the carbon itself, the efficiency of the arrangement for the chain reaction increases with ~~x~~ increasing temperatures within the range between room temperature and the highest temperature which is practicable in such machines. This in itself may be a reason for heating up the carbon-uranium system in order to start the chain reaction, and the temperature will then be maintained at a high level, perhaps at 800° during the operation of the machine by the heat which is liberated in the chain reaction.

In order to heat up the graphite-uranium system heating elements may be pushed into cavities in the graphite and these elements must then be withdrawn in order to start the chain reaction, otherwise their thermal neutron absorption may interfere with the chain reaction.

PATENT December 9, 1940

Use of Beryllium.

Beryllium may be used in the form of beryllium metal either cast in vacuum or pressed from beryllium flitters by applying a pressure of about in order to obtain the beryllium metal in the suitable shape and at a density between ~~15~~ 1.5 gm per cc and 1.9 gm per cc.

Beryllium may be used for instance in the form of spherical shells which surround a sphere of uranium metal, the radius of the uranium sphere being for instance 3 cm and the thickness of the beryllium shell being about 5 cm.

Beryllium may also be used in the form of a sphere of about 2 cm radius surround by a spherical shell of uranium metal which made up in two hemispherical shells, the uranium metal having a density of more than 9 gm per cc, preferably a density of about 18 gm per cc, and the uranium shell having a thickness of about 3 cm or more. This arrangement is less efficient from the point of view of the chain reaction but has the advantage of requiring a smaller total amount of beryllium metal which at present is rather expensive.

Beryllium may be used in the form of a cylindrical arrangement, in which case we have song cylinders of uranium surrounded by a cylindrical spherical shell of beryllium metal or cylindrical bodies of beryllium surrounded by a cylindrical shell of uranium metal. In the case of the cylindrical arrangement this second alternative, i.e. having the uranium outside and the beryllium inside is almost equally good as the other arrangement, namely having the beryllium outside and the uranium inside, from the point of view of the efficiency of the chain reaction, and it has the advantage of requiring a smaller total amount of beryllium.

Plane Arrangement as shown in Figure.

Arrangement in which cylinders having the form of tubes form a cage-like construction as shown in figure.

Memo P. Zero.

This invention concerns methods and apparatus which make it possible to maintain a nuclear chain reaction in uranium under conditions in which it is possible to utilize the heat liberated in the chain reaction for purposes of power production and also to obtain large quantities of elements produced from uranium itself in the process of fission, or produced by the capture of neutrons which are liberated in the chain reaction either in uranium or in elements which are exposed to the neutron radiation in the chain reaction.

According to this invention it is possible to maintain a nuclear chain reaction in a system composed of uranium and carbon, the latter element preferably to be used in the form of graphite. It is essential to choose a proper distribution of uranium within a mass of graphite, and the best resultsmay be obtained by using spheres of uranium distributed in the form of a close packed lattice within the graphite. It is desirable to have the density of the uranium as high as possible, and therefore uranium dioxide is ~~par~~ preferable to U 308, and uranium metal is preferable to uranium dioxide. It is also desirable to have as little scattering material within the uranium as possible, and for this reason again uranium metal is preferable to uranium dioxide, and the latter preferable to U 308.

The efficiency of the arrangement can be improved according to this invention by having a spherical layer of beryllium metal surrounding each uranium sphere. For instance, one may have a sphere of uranium metal of about 10 cm diameter surrounded by a spherical layer of beryllium between 2 - 3 cm thickness. Such spherical layers of beryllium can be produced by putting together two shells corresponding to two halves of the sphere, and each shell can be produced by pressing beryllium flakes into a mould, using pressures of about 4 tons per cm^2 or preferably even higher pressures which result in even higher densities. Densities between 1.5 gm per cc and 2 gm per cc can be obtained by this method. The function of the beryllium in the chain reaction consists in the following: Fast neutrons emitted from a uranium sphere under the action of thermal neutrons will pass through the beryllium layer which surrounds the sphere and will disintegrate some of the beryllium atoms in such a way as to liberate additional neutrons from the beryllium. This leads to an increase in the total number of fast neutrons which are produced from uranium and beryllium together for every thermal neutron absorbed by uranium over the number of fast neutrons liberated from the uranium alone for one thermal neutron absorbed by uranium. The significance of this number for the possibility of maintaining a divergent chain reaction is discussed further below within the framework of a general theory of a chain reaction composed of uranium and carbon. It may be added that neutrons having a velocity above 1.6 m.v. can be expected to be capable of liberating neutrons from beryllium, and that from the investigations published by Szilard and Zinn

it can be deduced that a considerable fraction of the neutrons emitted in the fission of uranium caused by thermal neutrons have an energy above that value.

It is a particularity of this arrangement that its ~~xxxxfficiency~~ efficiency strongly increases with the density of the uranium. Commerical uranium oxide U 308 has a density of 7. The bulk density of the commercial product is about 4. This uranium oxide can, however, be reduced to uranium dioxide which has a density of about 11. The bulk density of the powdered uranium dioxide is, of course, considerably less, but by applying pressures between the bulk density can be increased to approximate the true density of the crystal. By using a suitable mould uranium dioxide can be pressed into cylinders which have about the same height as their diameter, or can be pressed into the form of spheres, and the dioxide used in the proposed arrangement in the form of half-spheres which are made up out of two half-spheres.

An even greater density can be reached if uranium metal is used. Powdered metal can be pressed into moulds,as discussed above in connection with uranium dioxide. If the metal is obtained from uranium oxide by reduction with calcium hydride itmay contain considerable quantities of hydrogen so that the scattering of thermal neutrons may be considerably higher for this material than for pure uranium. This increased scattering is disadvantageous from the point of view of the efficiency of the chain reaction, and it is therefore advisable to free the uranium from hydrogen. Uranium metal is reduced from uranium oxide by carbon in an induction furnace and subsequently pressed into moulds to obtain the metal in the desired geometrical form.

Pat

for 10,000 Volt 80% probab.

Reasons for small Carbon absorption.

Carbon has two isotopes C12 and C13, the absorption of thermal ~~n~~ is set by level spacing and the position of the first resonance level. The level spacing may be estimated to be between 10000 and 100,000 Volt for C12 and ~~between 1000 and 10000 Volt~~ ten times smaller for C(13) × Accordingly ~~it is practically certain that~~ we can count on the first strong level for C12 ~~will be~~ being beyond 1000 Volt and ~~for~~ that will be beyond 1000 V/4 ~~for theoretical reasons~~ accordingly we may expect ~~C thirty~~ C12 to have an absorption below 0.0005×10^{-24} cm^2 and C(13) to have an abs cross sect below 0.05. Since ~~there is the less than 1%~~ relative abundance of C13 is less than 1% we can count on the total abs. of ordinary Carbon to be less than 0.001. — and it will very probably be small

The position of the first res. level it can not a priori be predicted it can be with about equal probability anywhere between 0 and the first resonance level × ~~Accordingly it is practically~~

Put.

This is certainly sufficiently low to make a chain reaction possible ×

This does not mean however that for this any ordinary brand of graphite ~~can be~~

~~The~~ Spect. pure carbon would certainly be suitable but

graphite, boron and rare earths. —

(1)

Johnson ~~for calculating~~

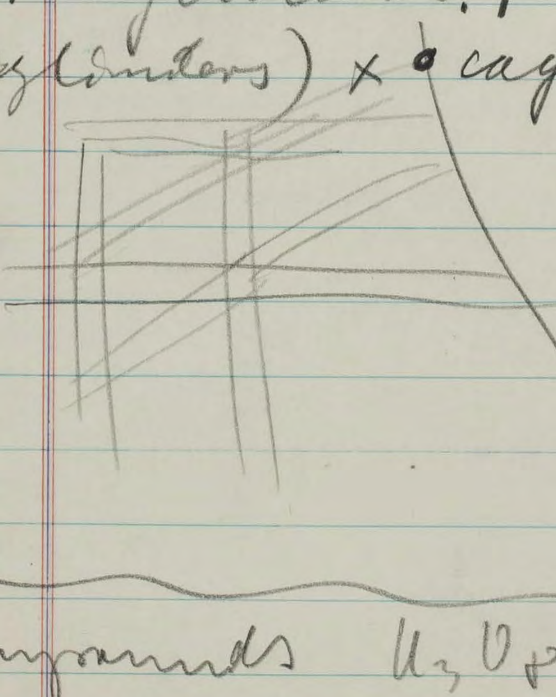
See:
Urey | Dunning | Rayram

Term intermediate scale experi-ment

Pat Memo

Uran metall advantage of high density 1.) total U amount may be kept small. 2.) ~~It is possible to fast neutron reaction~~ advantage of metall (no oxygen!) fast neutron reactions contribution 3.) small amount of Be necessary 4.) small amount of Bi

Arrangements: lattice of spheres or (cubes or cylinders) × cage construction from tubes

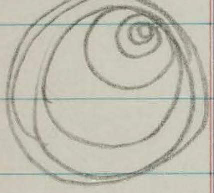
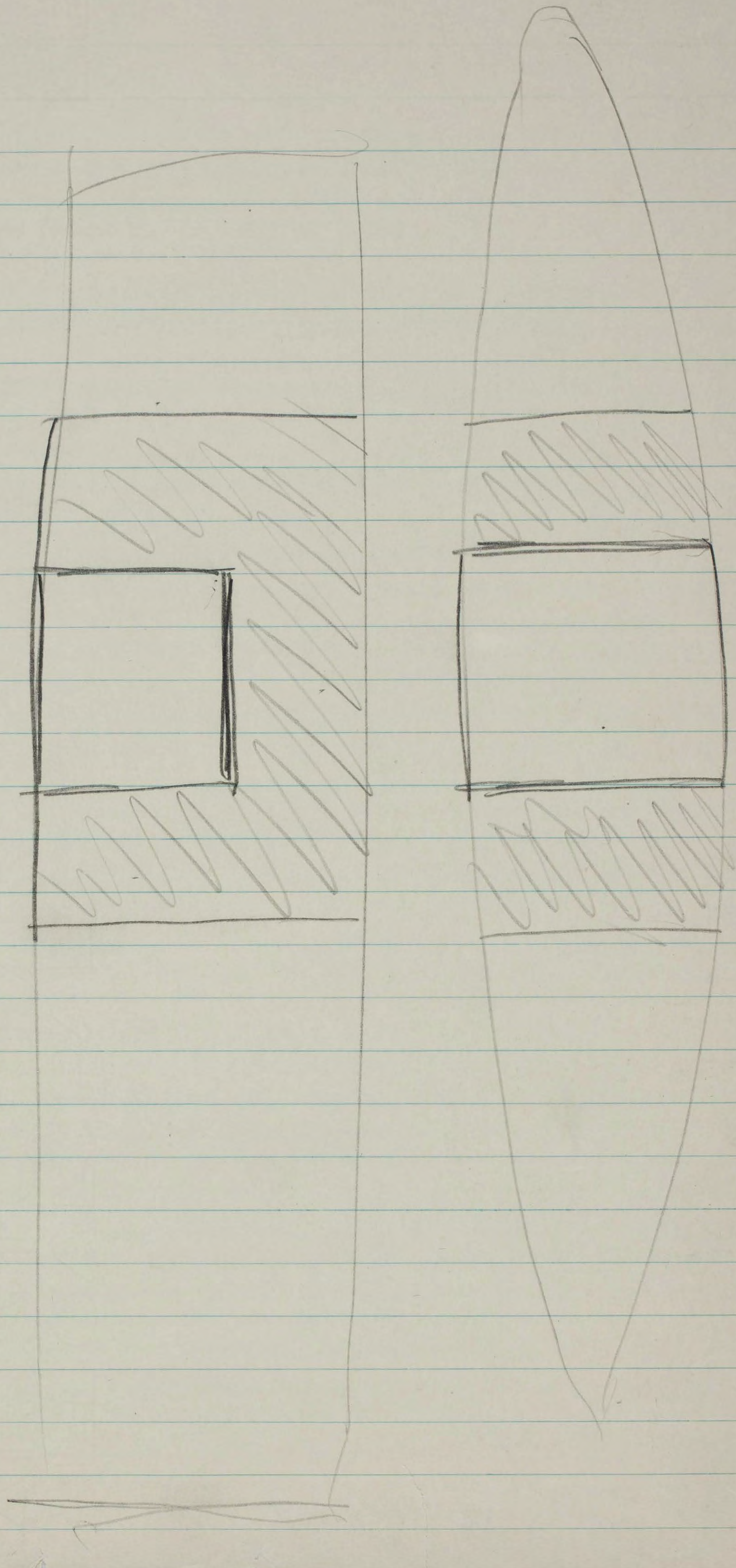


tubes cylinders or

Compounds U_3O_8 UO_2 US_2 U_2S_3

24

pages

Memo

Pats and Breda

We may count on (C) being small, —

Technical question

Point of views

Arrangement.

~~In the case of the spherical shape it is ear~~

Treatment of res. elec. assumption

higher levels. —

Importance of ratio U/C

density enters O.K. for sphere

higher densities

smaller density may be of advantage in case of TUBES

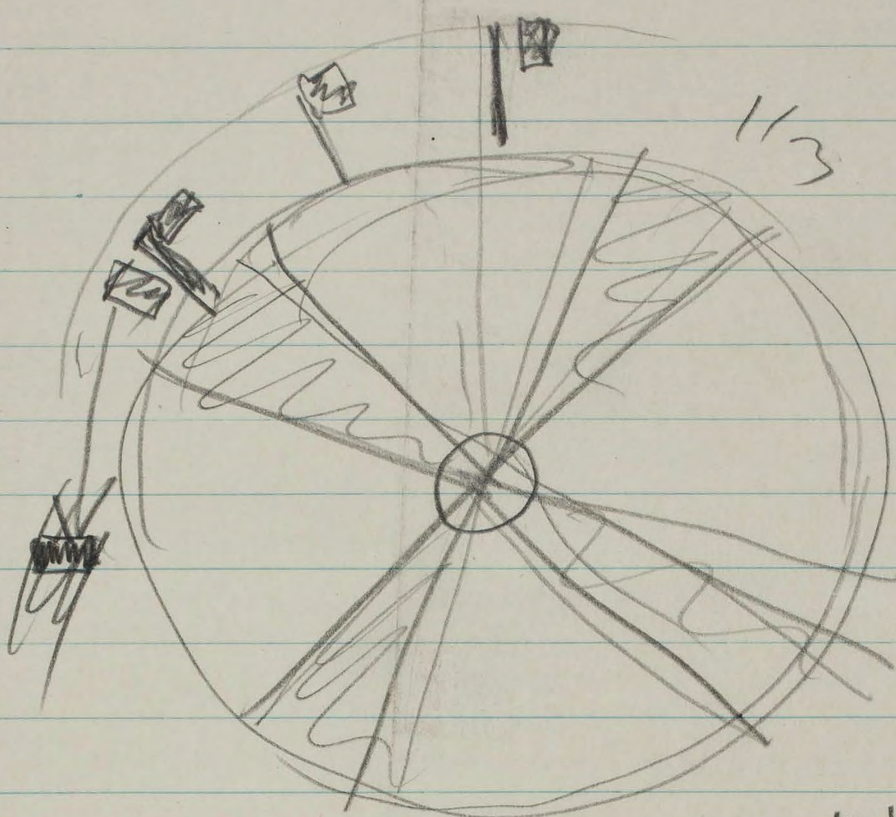
Calculate

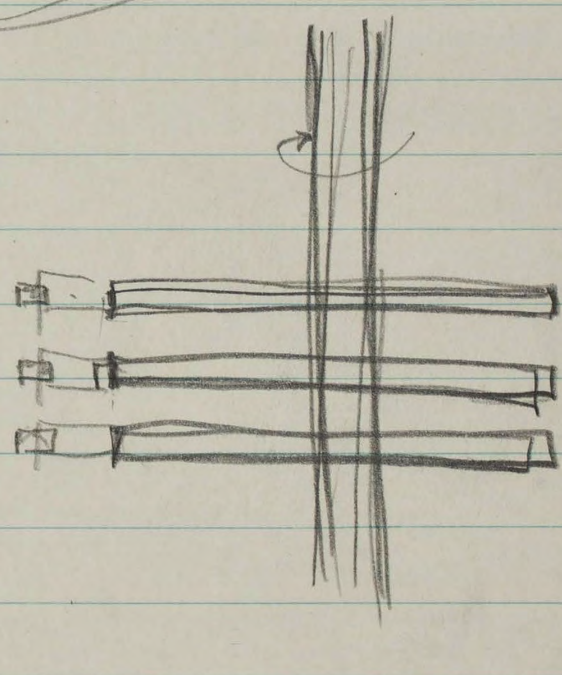
Thickness in case of

Plane layer

Write Placsek cylindrical case

Regler



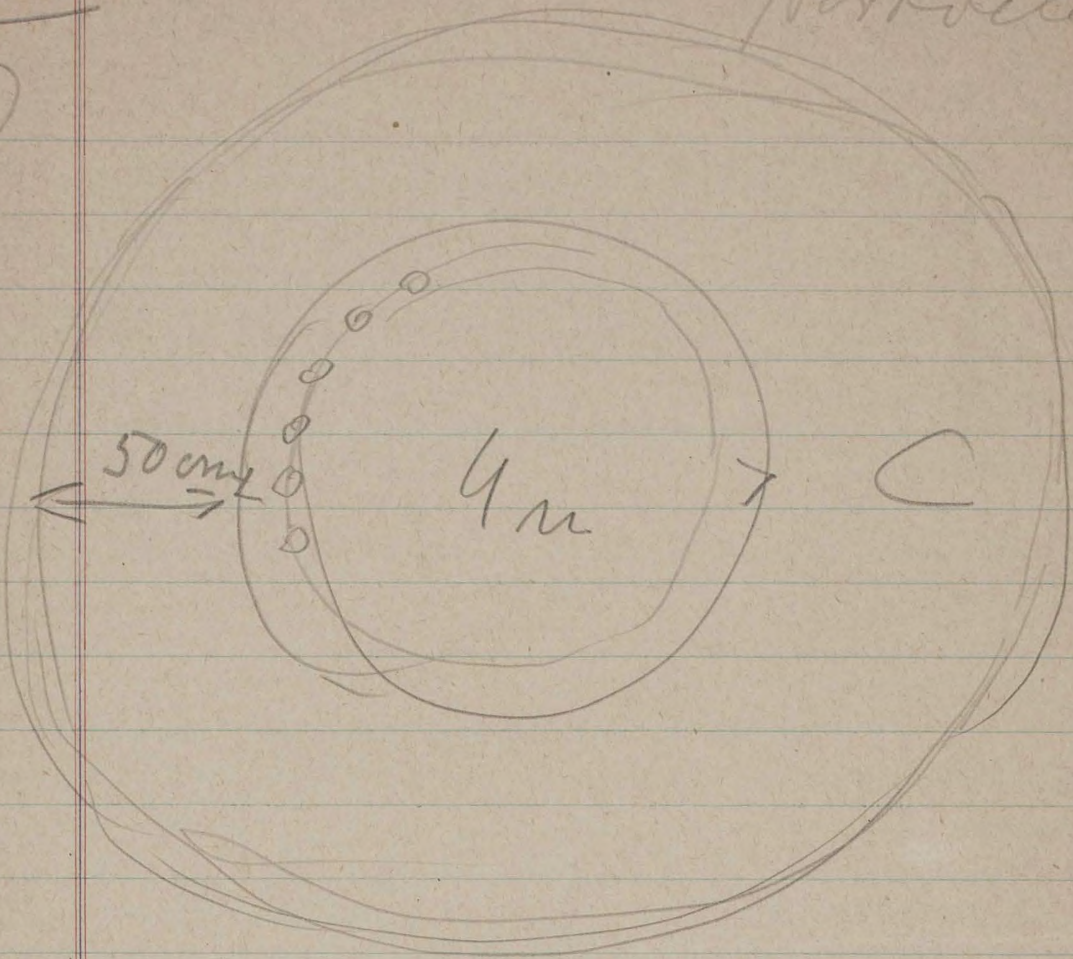


Dec 24

Bet

No 2 Radioactive fission particles

(1)



if 1.5 n are emitted 1/3 of U can be transformed

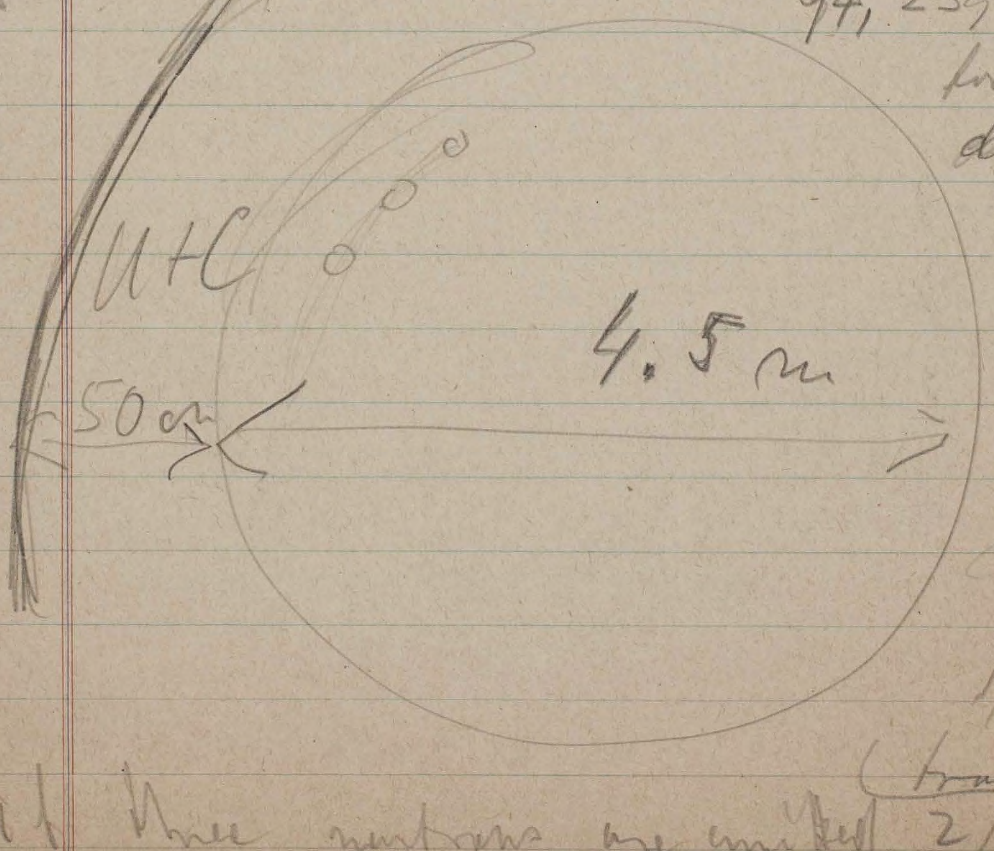
Radioactive capture

if 2 neutrons are emitted per captured neutron from 94, 239 then

for one 94 which dies we get two 94 and half of U gets

• • •

× × ×



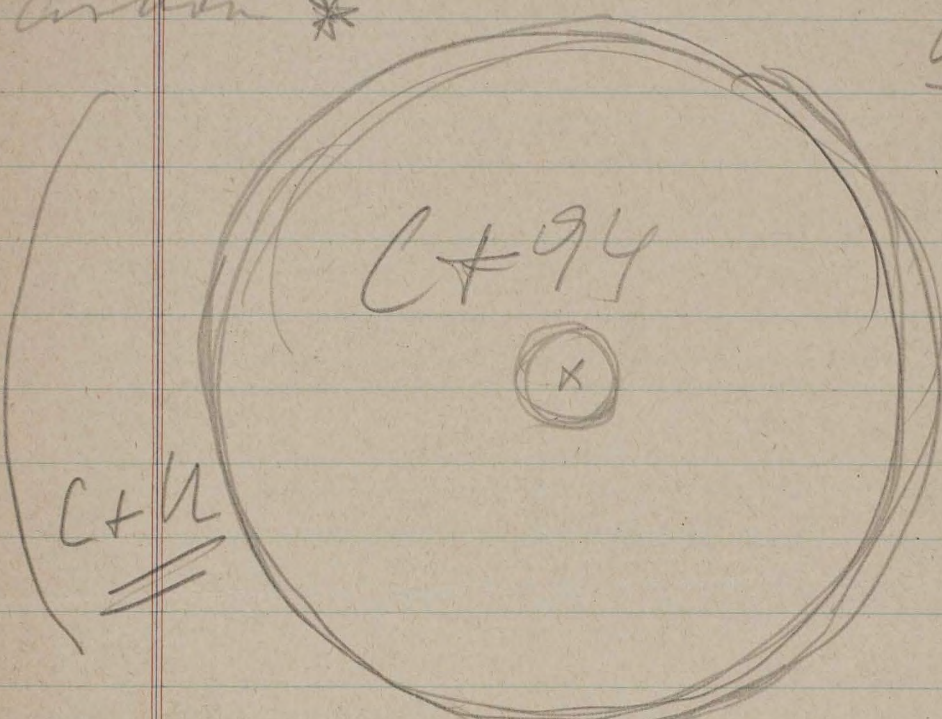
transformed to 94 while 1/2 is burned

if three neutrons are emitted 2/3 can be transformed

Pat

Dec 24 Page (3)

In forming element 94 use enough of it ~~at~~ and oxide carbon *



0.003

$\frac{20}{1000} = 0.02$

1 : 1000 Atoms

1 : 50 in weight

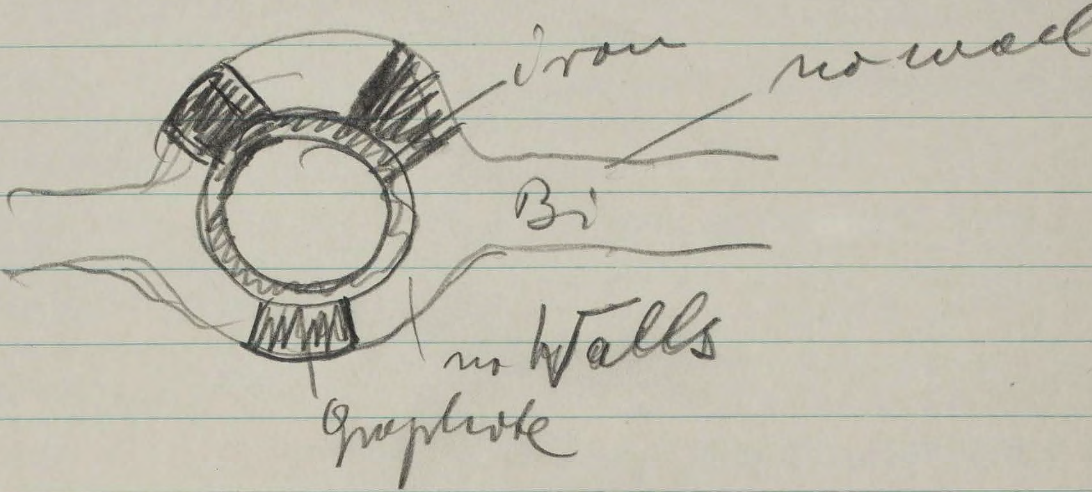
one may wish to use as much as

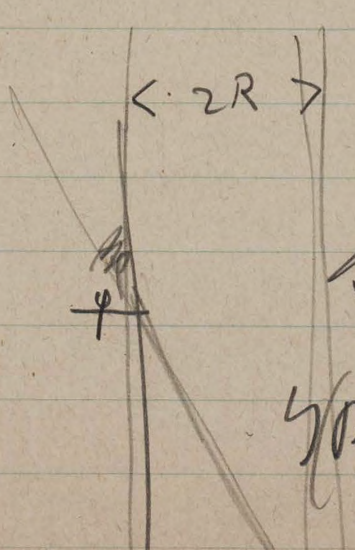
element 94 either fission or radioactive capture, if latter

We obtain $^{240}_{94}$

if α emitter U 236

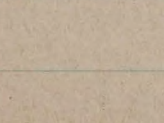
~~Second~~ (2) Edg

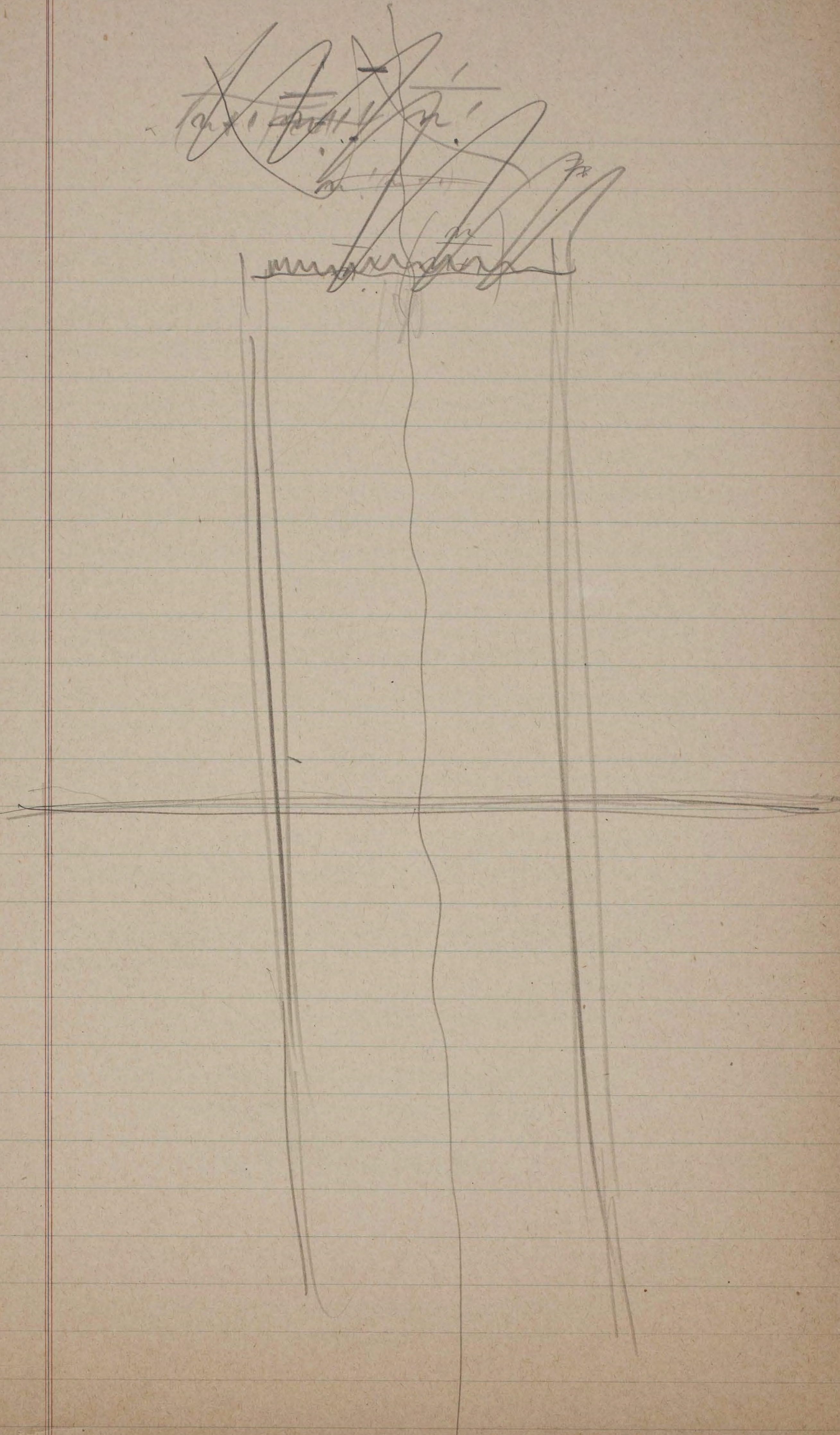




$$y(R) = \int_0^{\frac{\pi}{2}}$$

$$y(R) \frac{\qquad}{\int_0^{\frac{\pi}{2}}}$$





Pat Dec. 24
Page 4

if ~~1~~+X number of neutrons emitted

$1-X$ 1 X

$\cdot\ \cdot$

transformed $\dfrac{1-X}{1+X}$

---

if 2 neutrons are needed to make 240 from 238

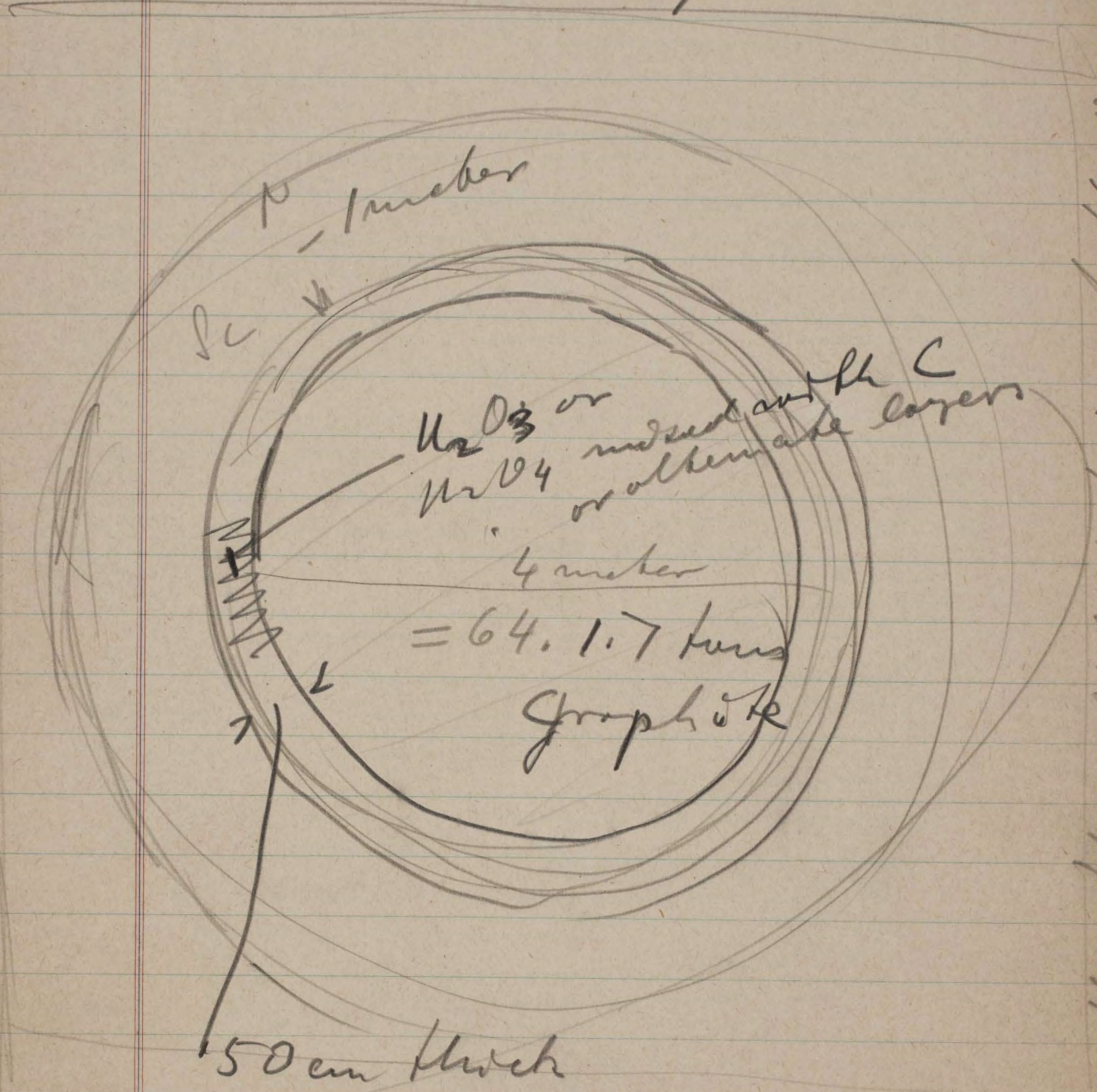
$2+y$

$\dfrac{y}{2+y}$

Rot Dec 24 No1 339

Drawings

with and without layer



Graphite layer [illegible] cm thick

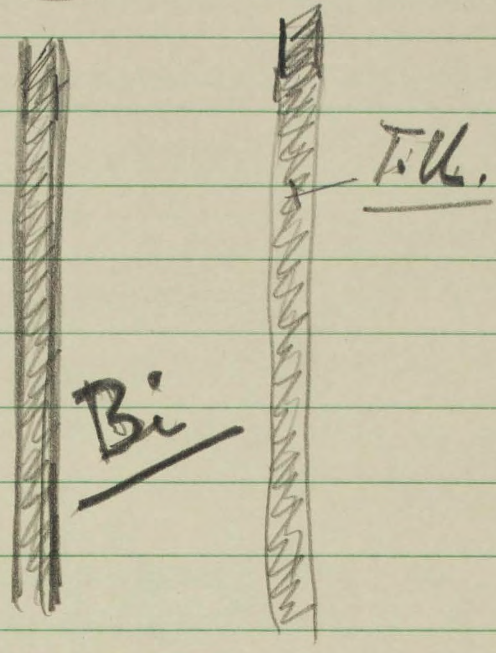
Ratio U atom to C atoms

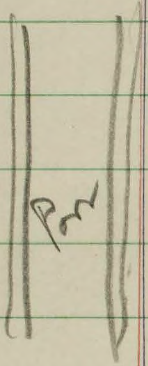
1 20

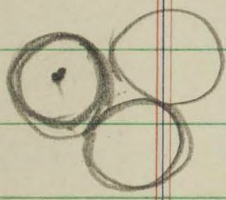
means equal weight; if U density 6 C density 1.7 less than 1/3 of vol is taken by U_3O_8

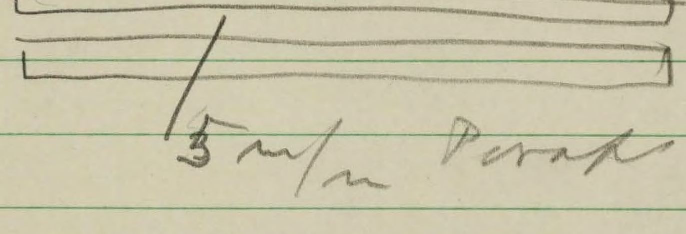
Separated ~~isotopes salt~~ transuranes

best arrangement









Put Boron in to protect U_{235}
and other thermal fission elements
or use subnormal Uranium
add T.U to ~~normal~~ normal or subnormal U

If one element emits ν_1 ~~[illegible]~~ neutrons in undergoing fission and if ~~[illegible]~~ n neutrons are needed to produce it from U_{238} ~~then neglecting [illegible]~~

~~in which~~ $\frac{\nu_1 - n}{n}$ ~~ratio of~~ number of atoms of element produced to number of 238 destroyed

~~If [illegible] $\nu_1 - n$ is ν_1 element can not be produced by burning 238 but can be produced from 238 by burning 235~~

~~the fraction of~~

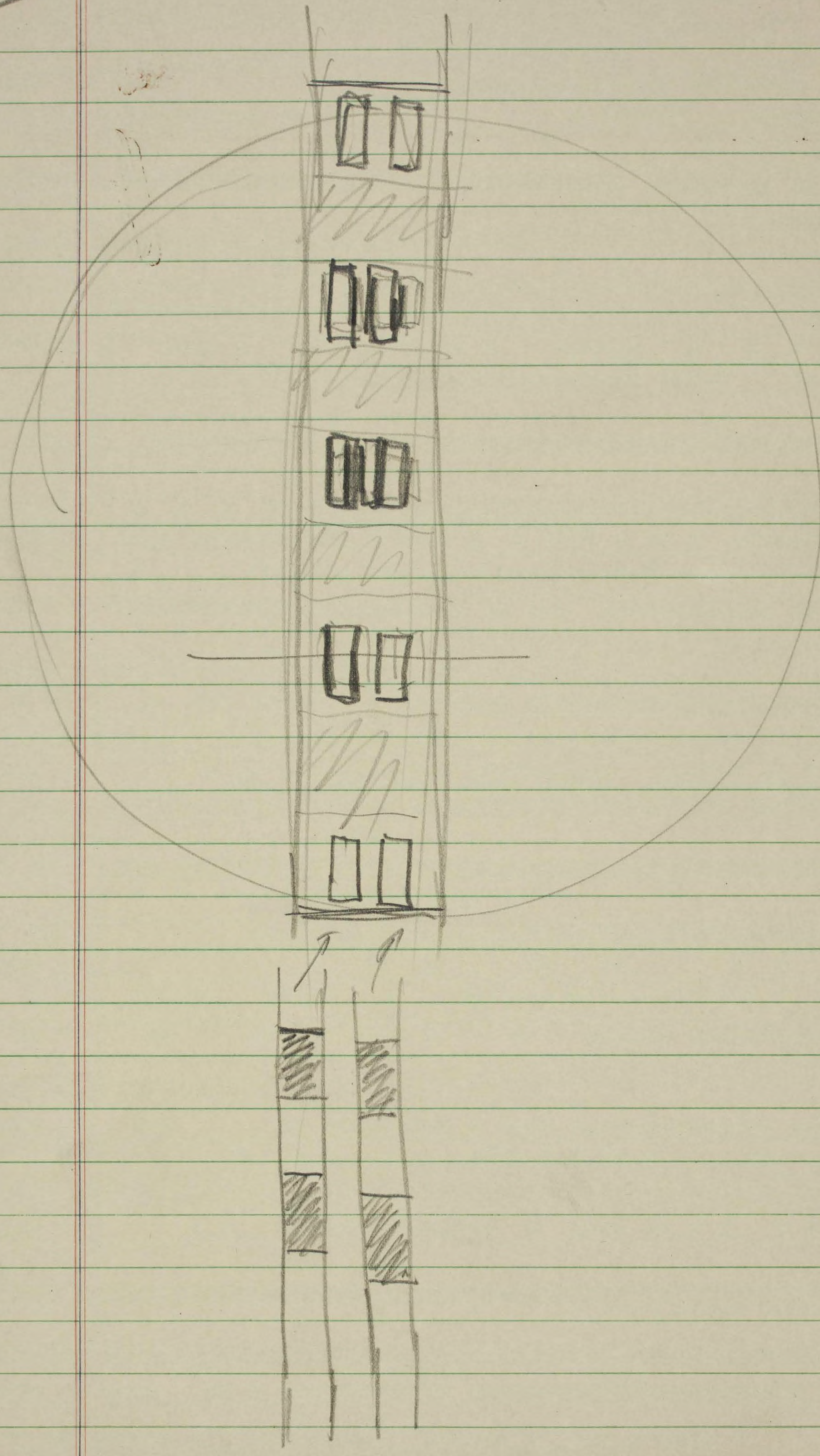
~~then~~ $x(\nu_1 - n)$ ~~then a fraction~~

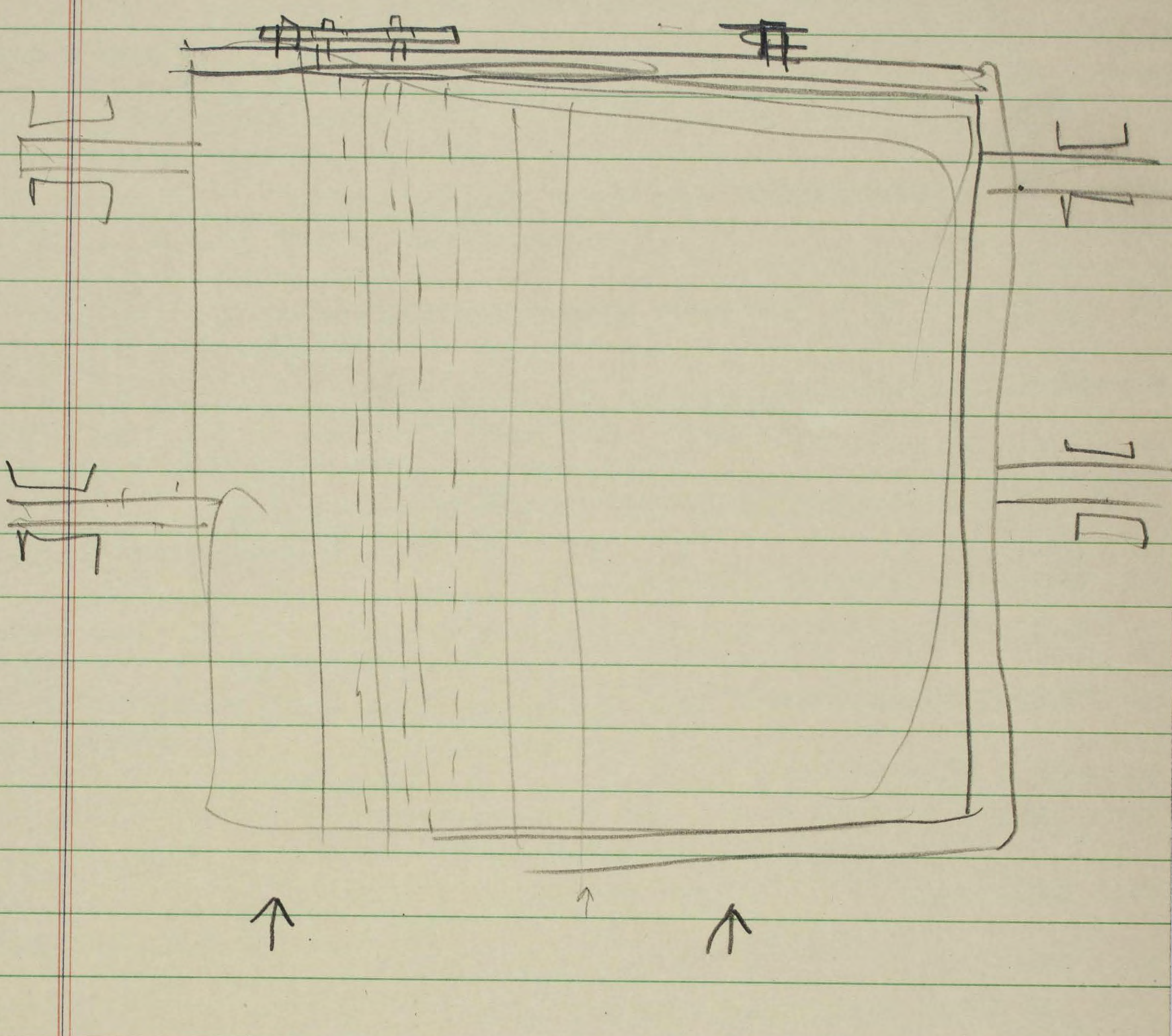
Atoms of the element are produced per U_{238} atom destroyed where

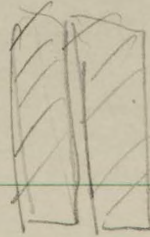
x

1c

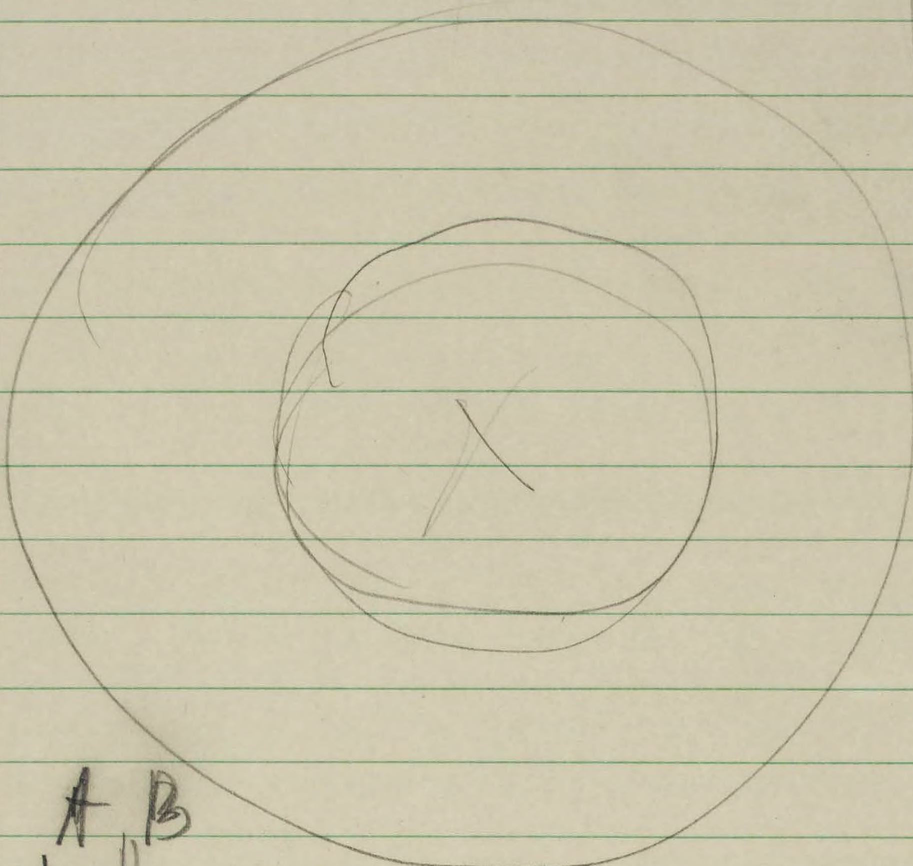
Burned out A

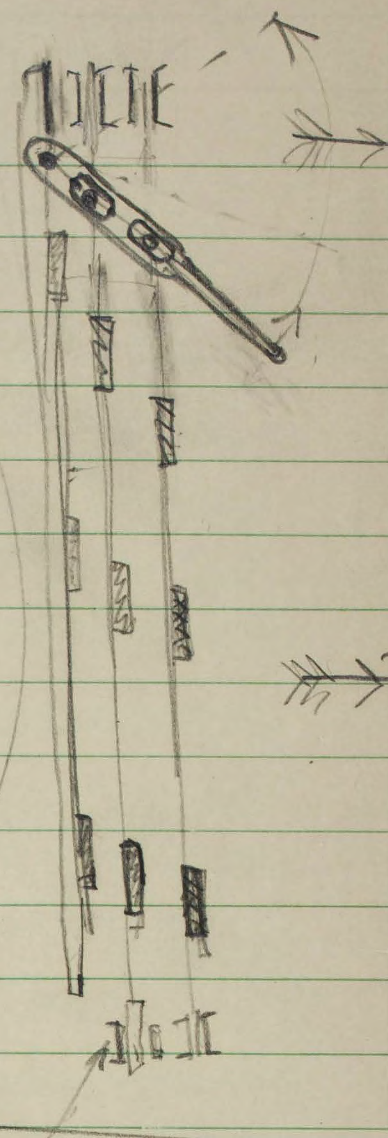


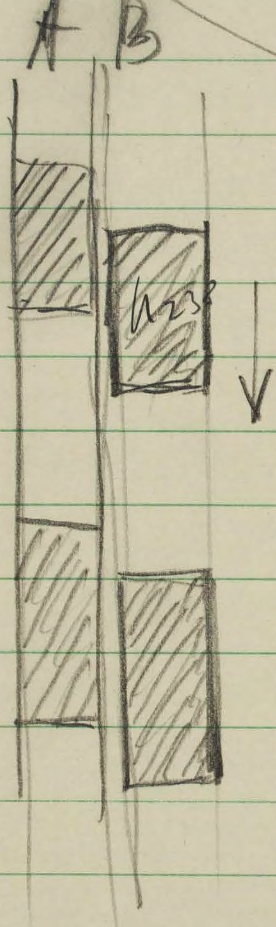


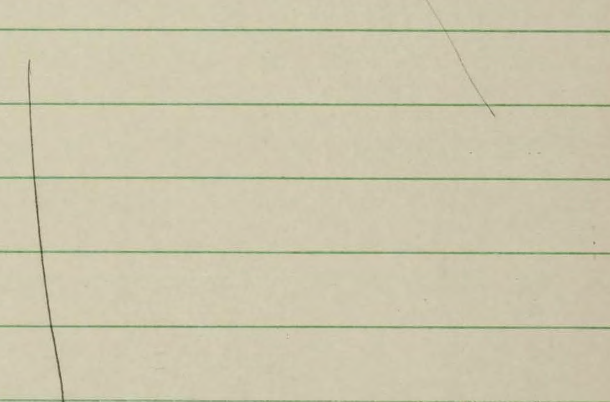


Print out U





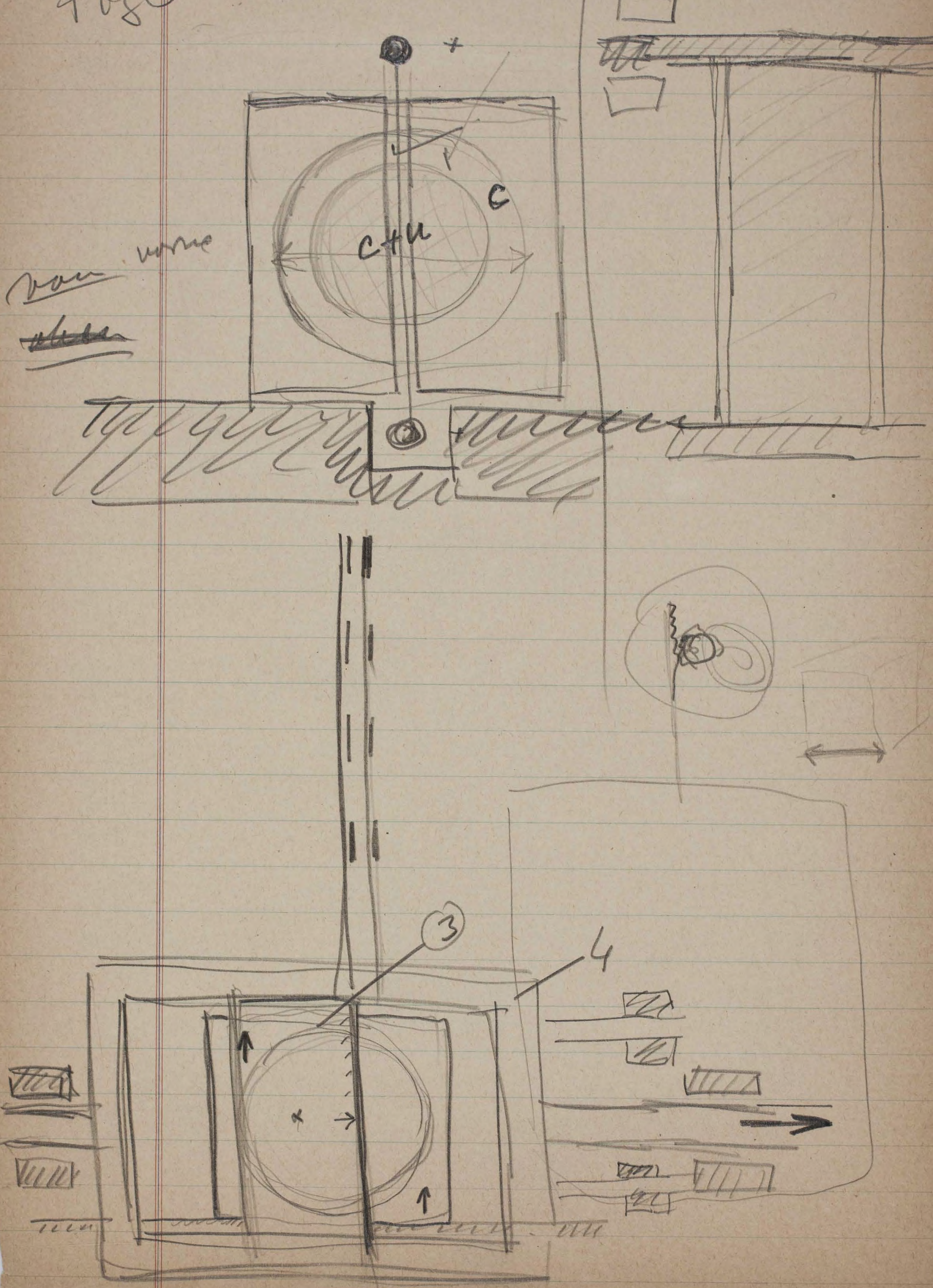




7
3

Use current and U for [illegible]

Fig (1) Dec 29-40



Dec 29 40

$\frac{2\pi \times 3}{\frac{4\pi}{3}}$

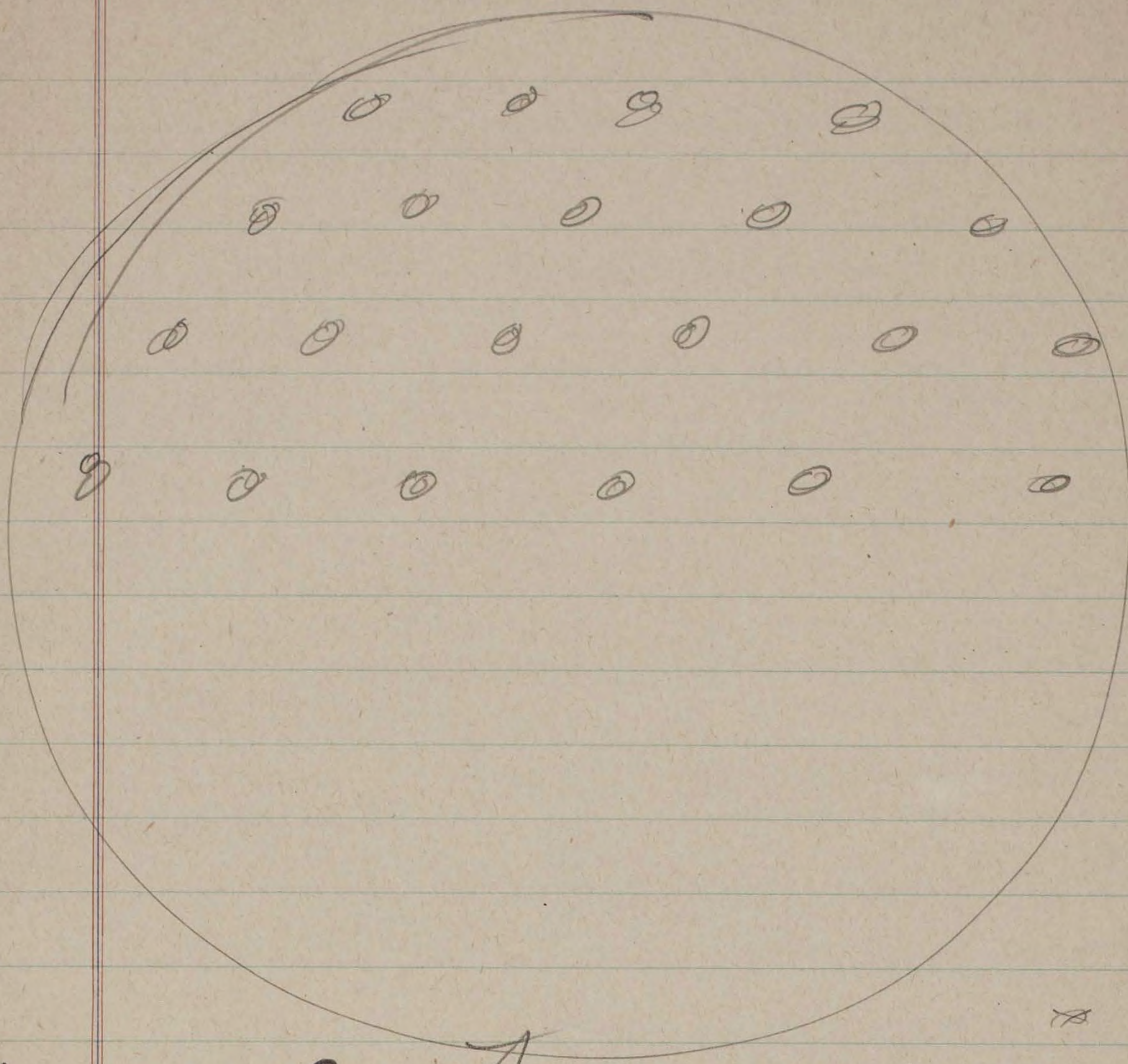
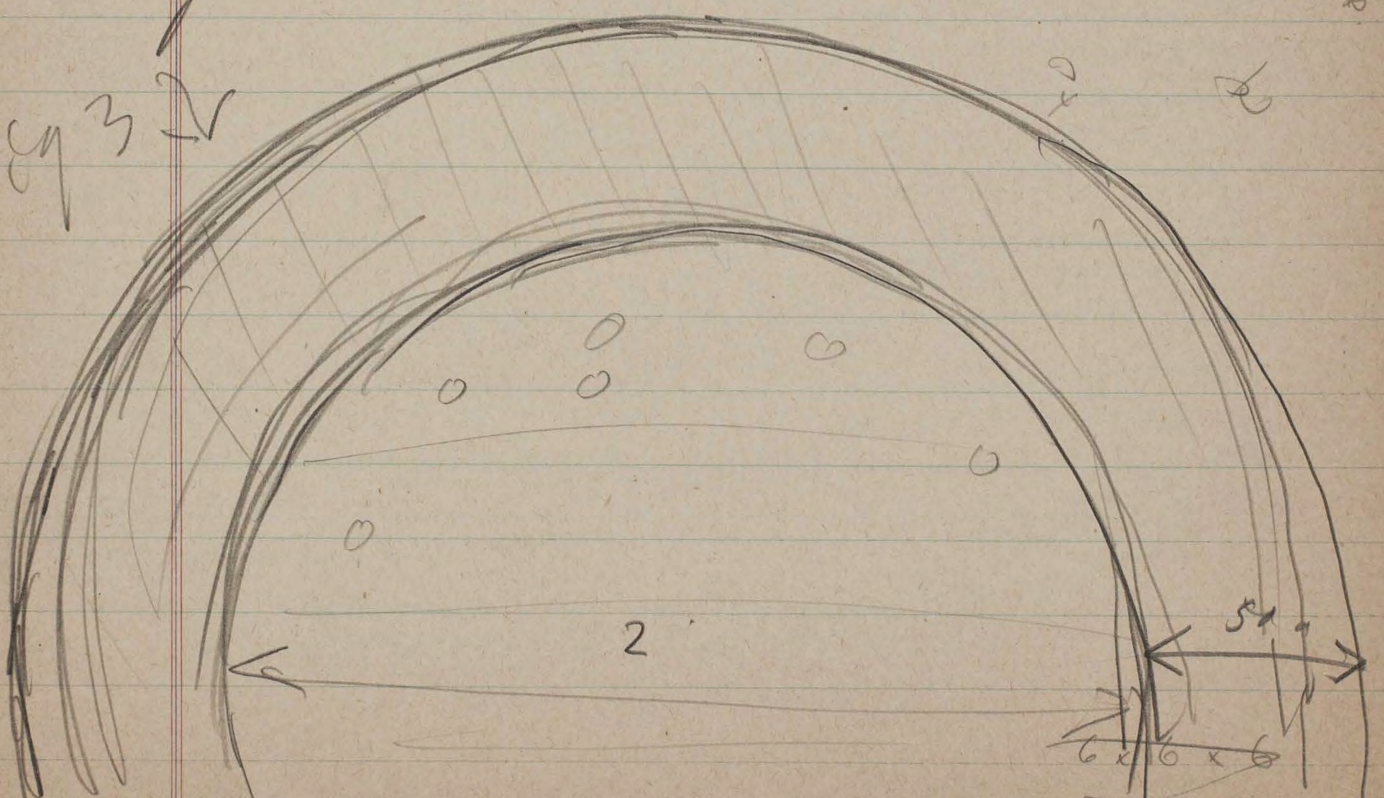


Fig. 2

Fig 3



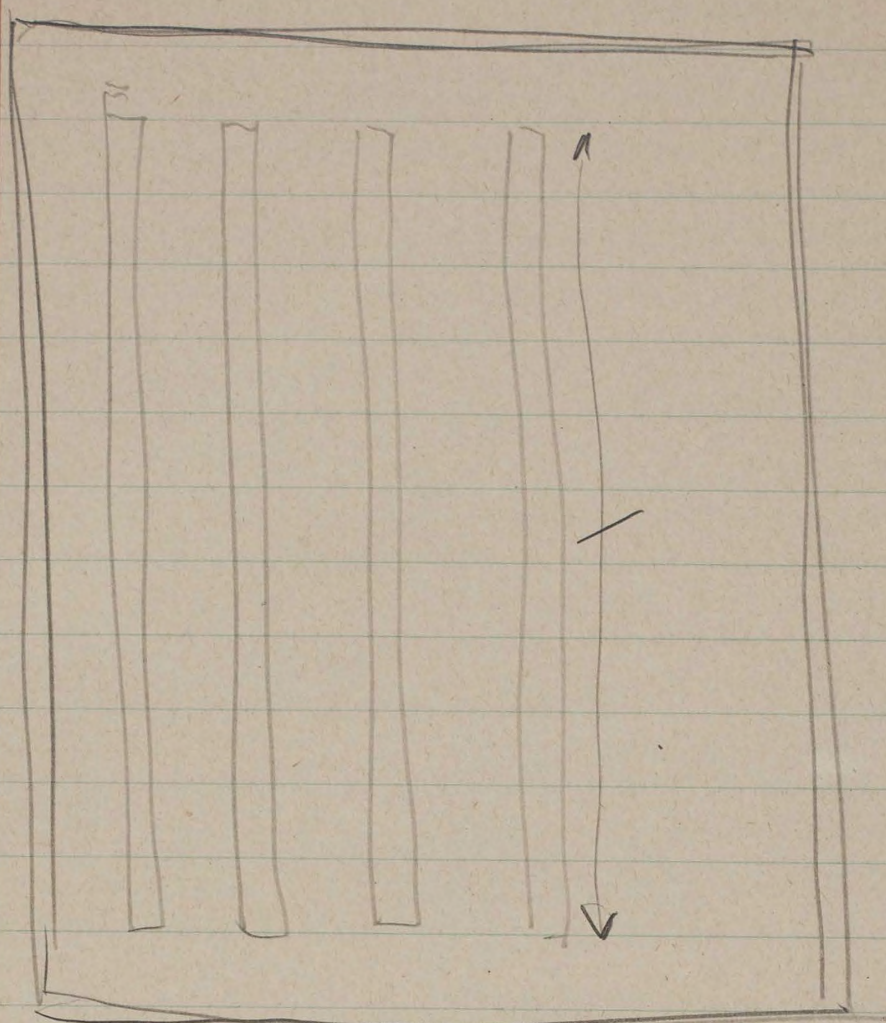


Fig 4

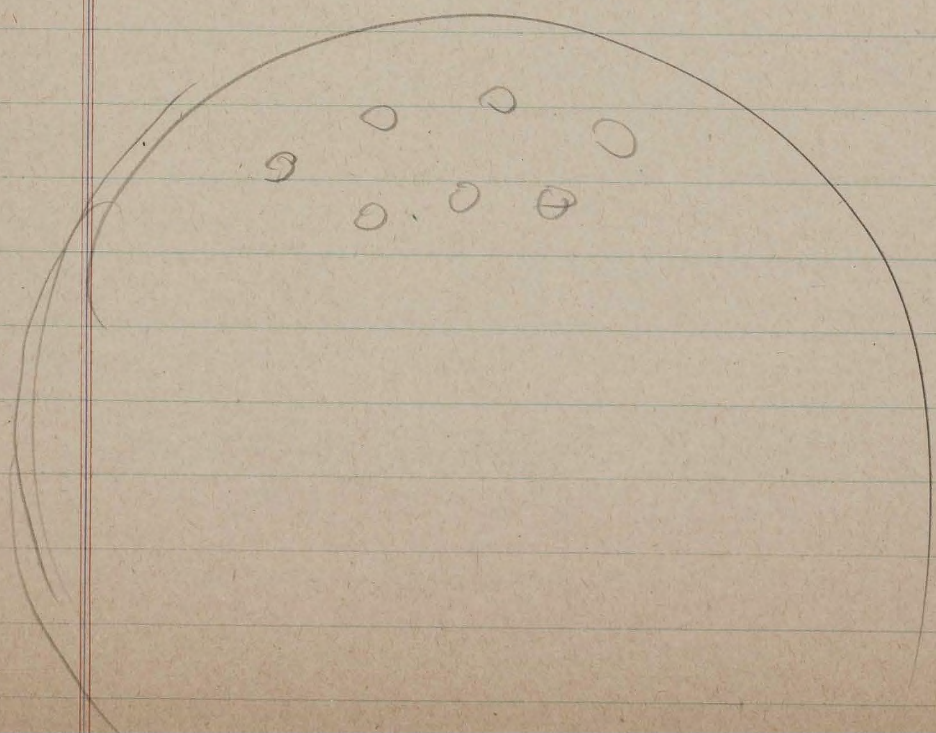
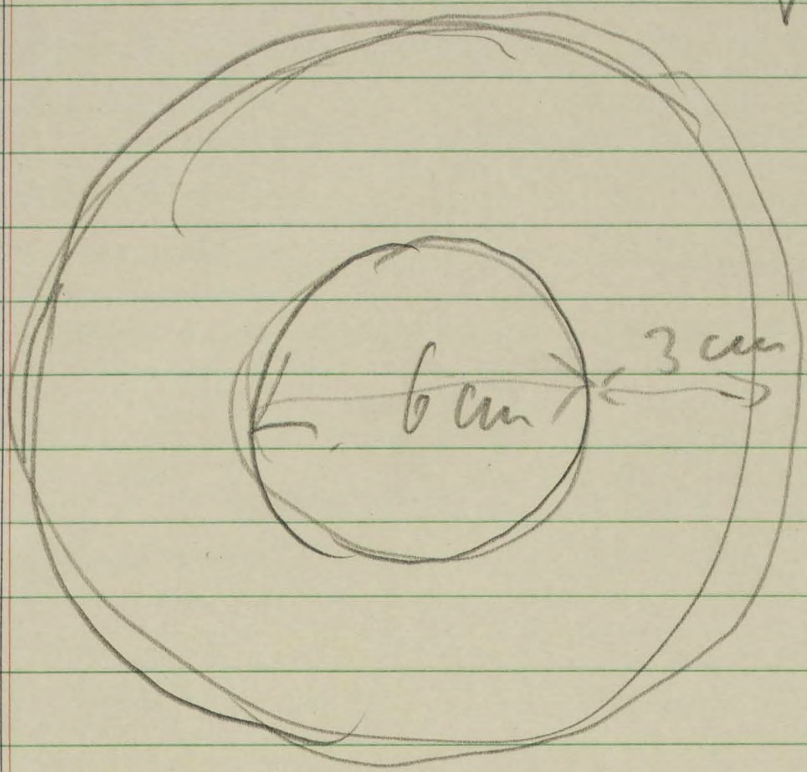


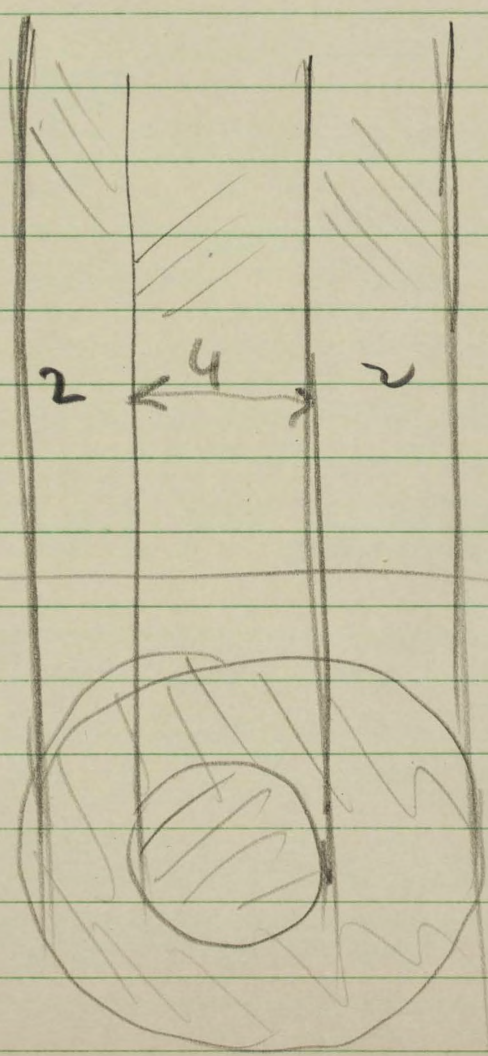
Fig 4b

Be

Sphere



Cylinder



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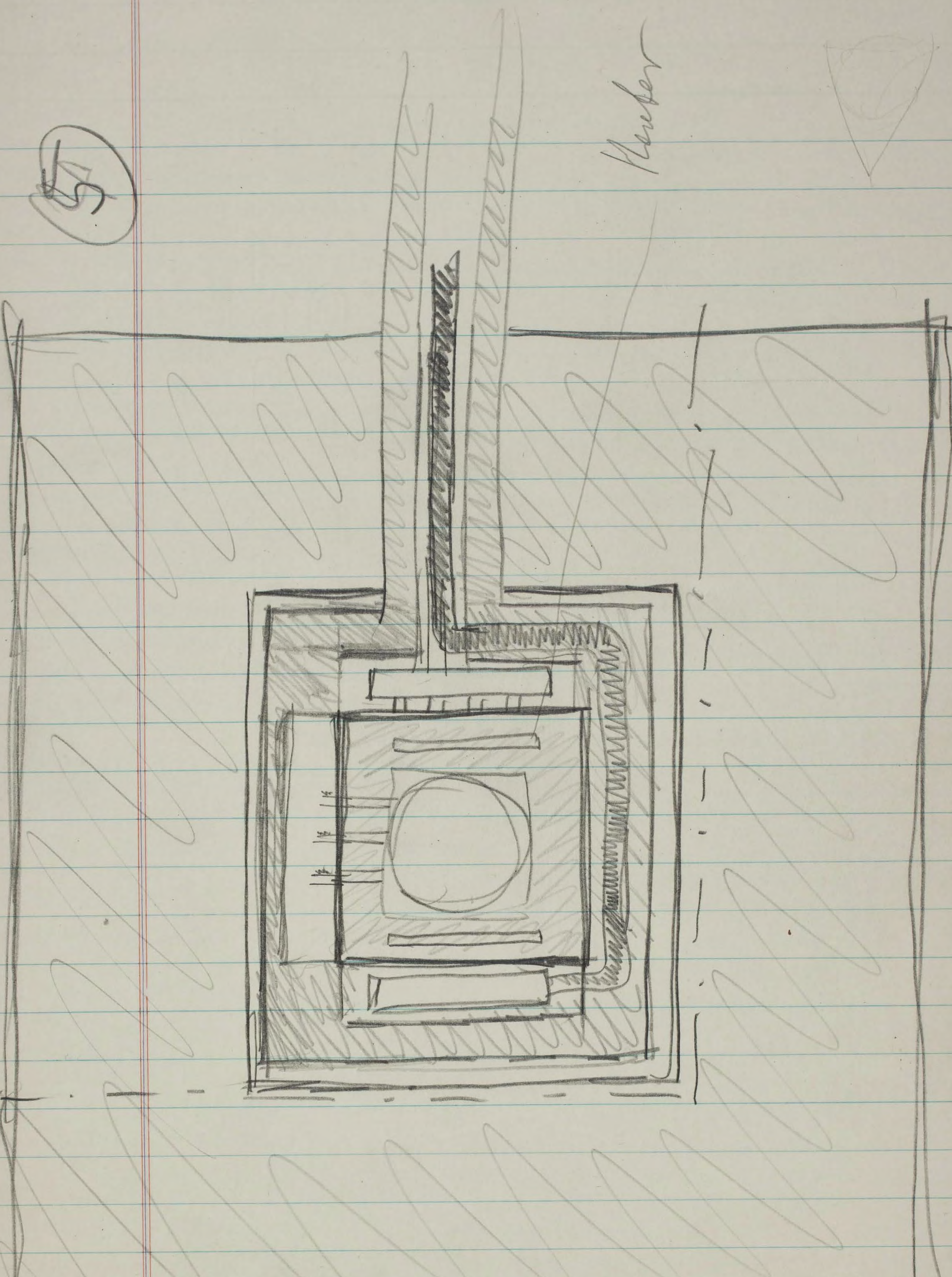

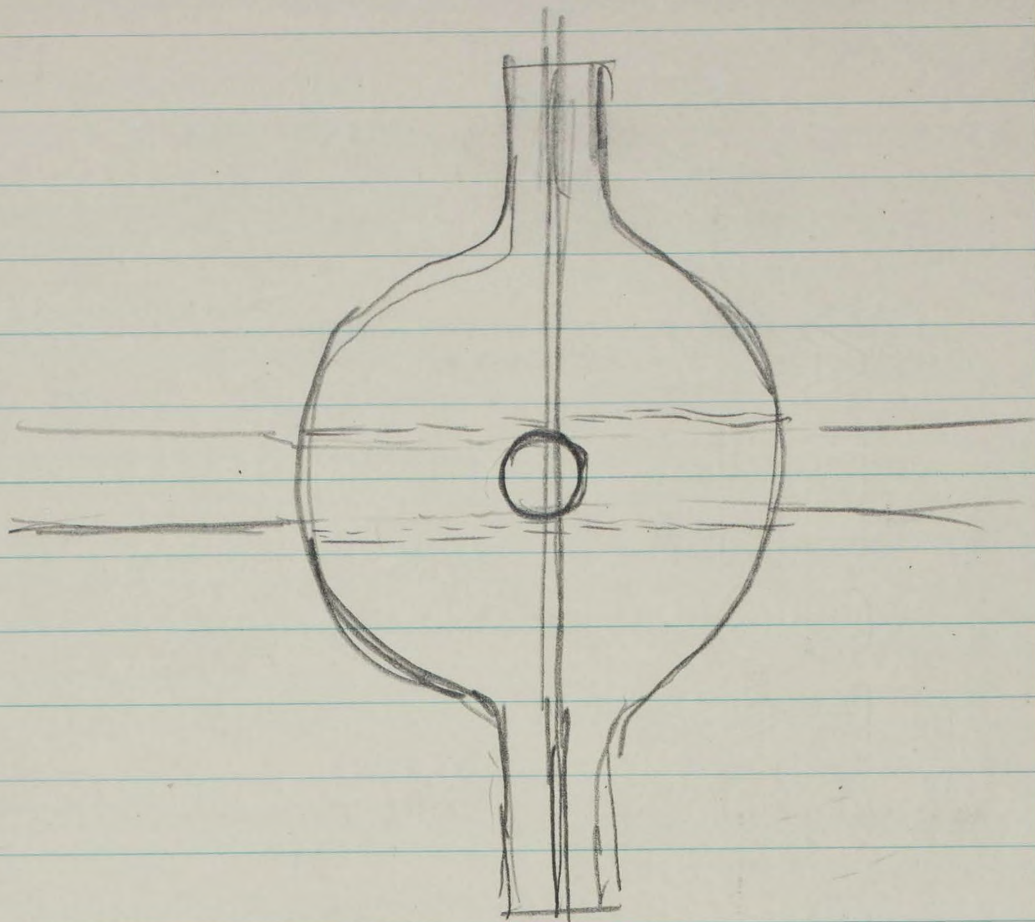

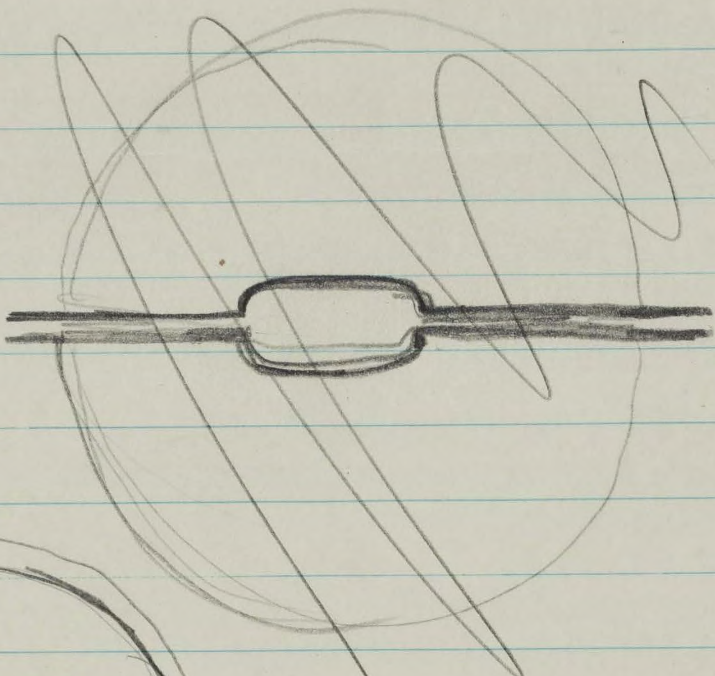

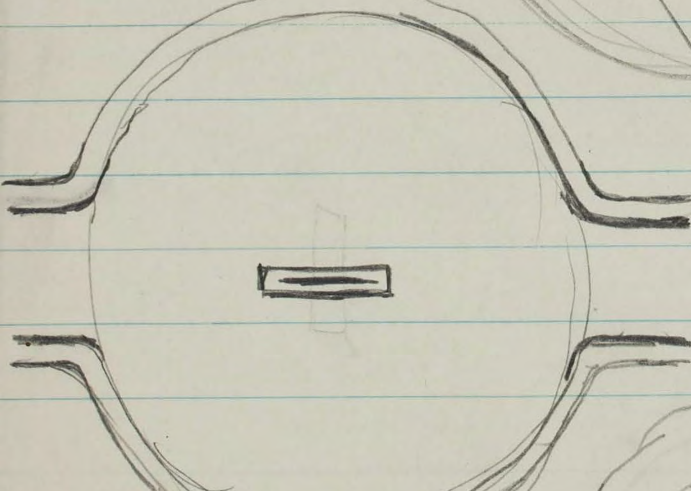

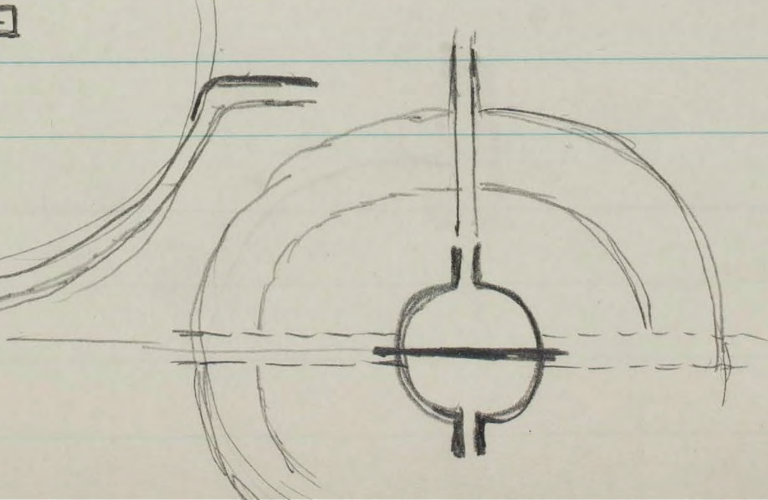

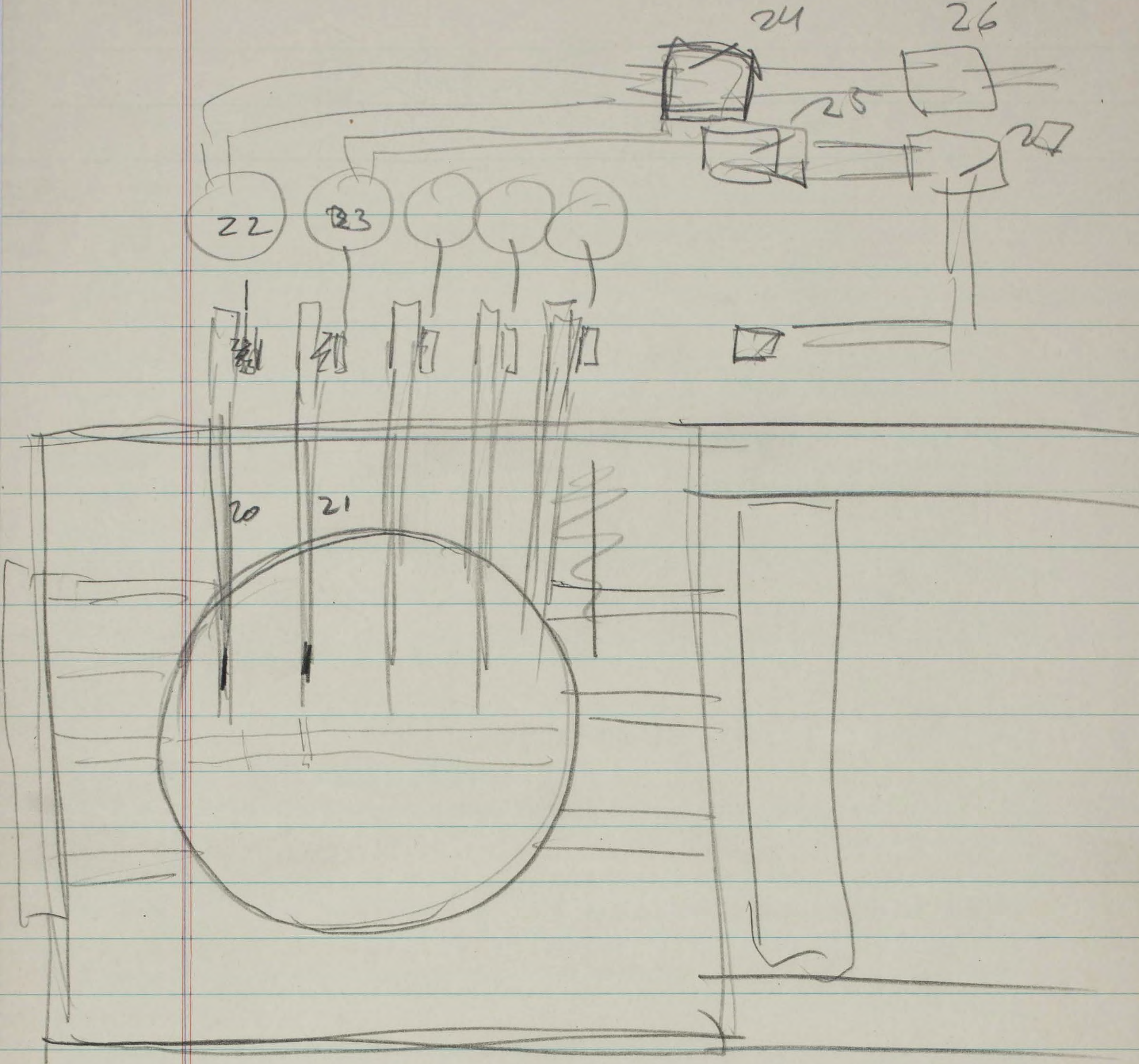

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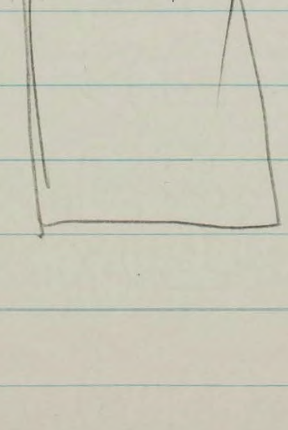

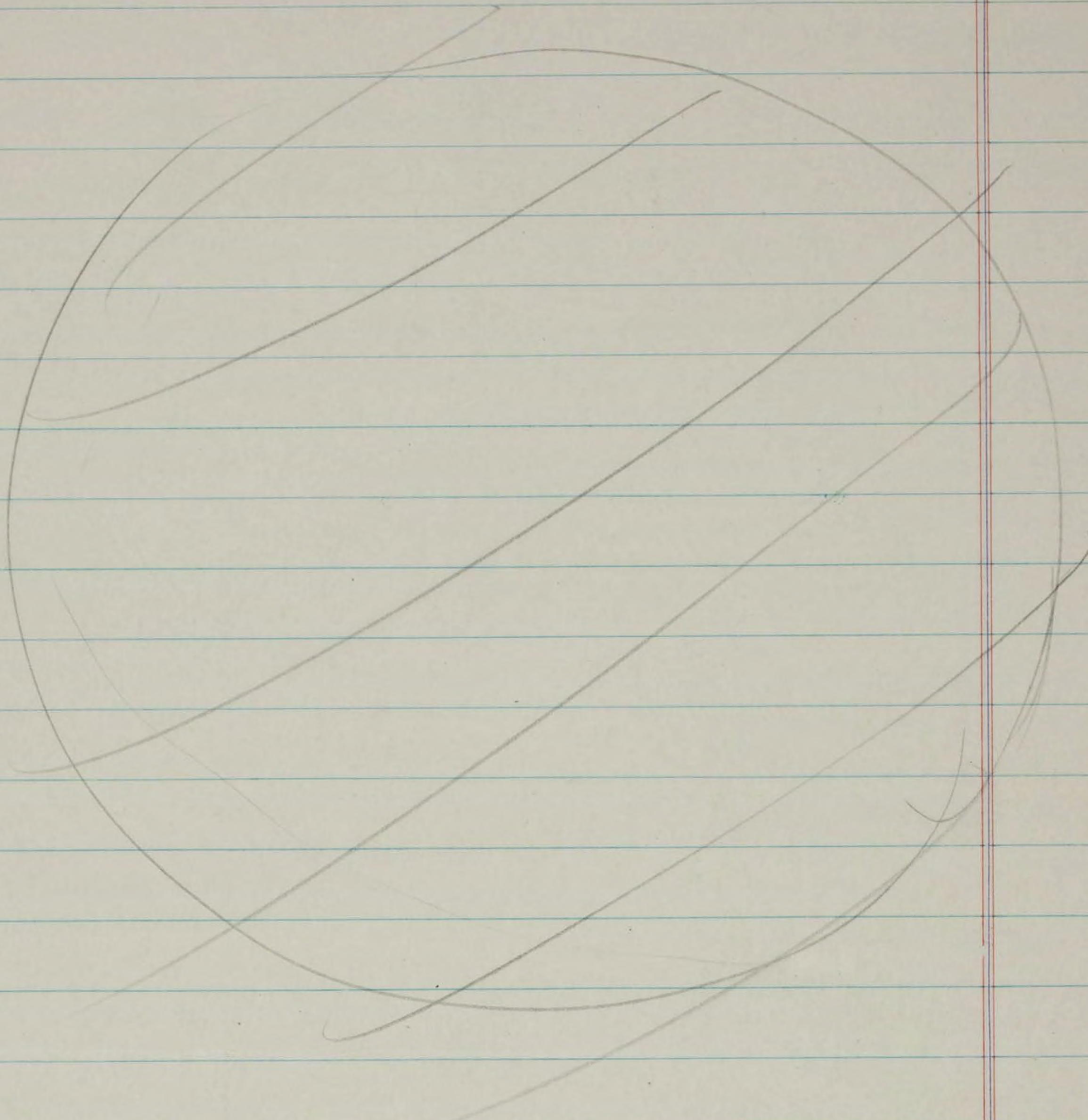

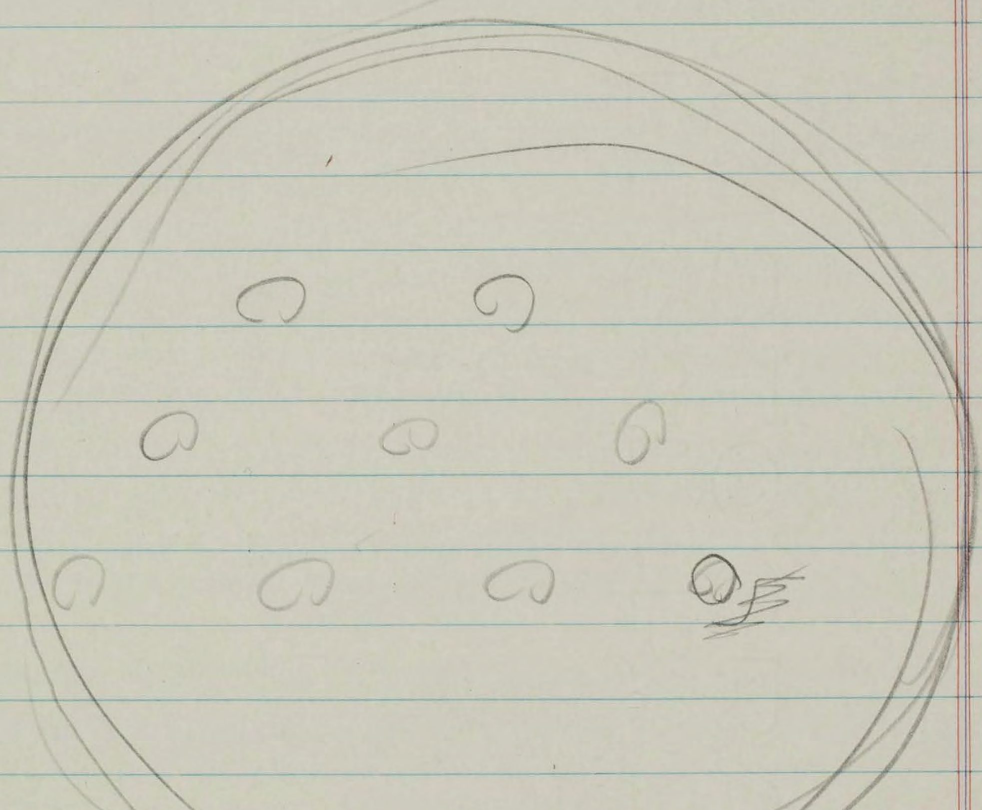

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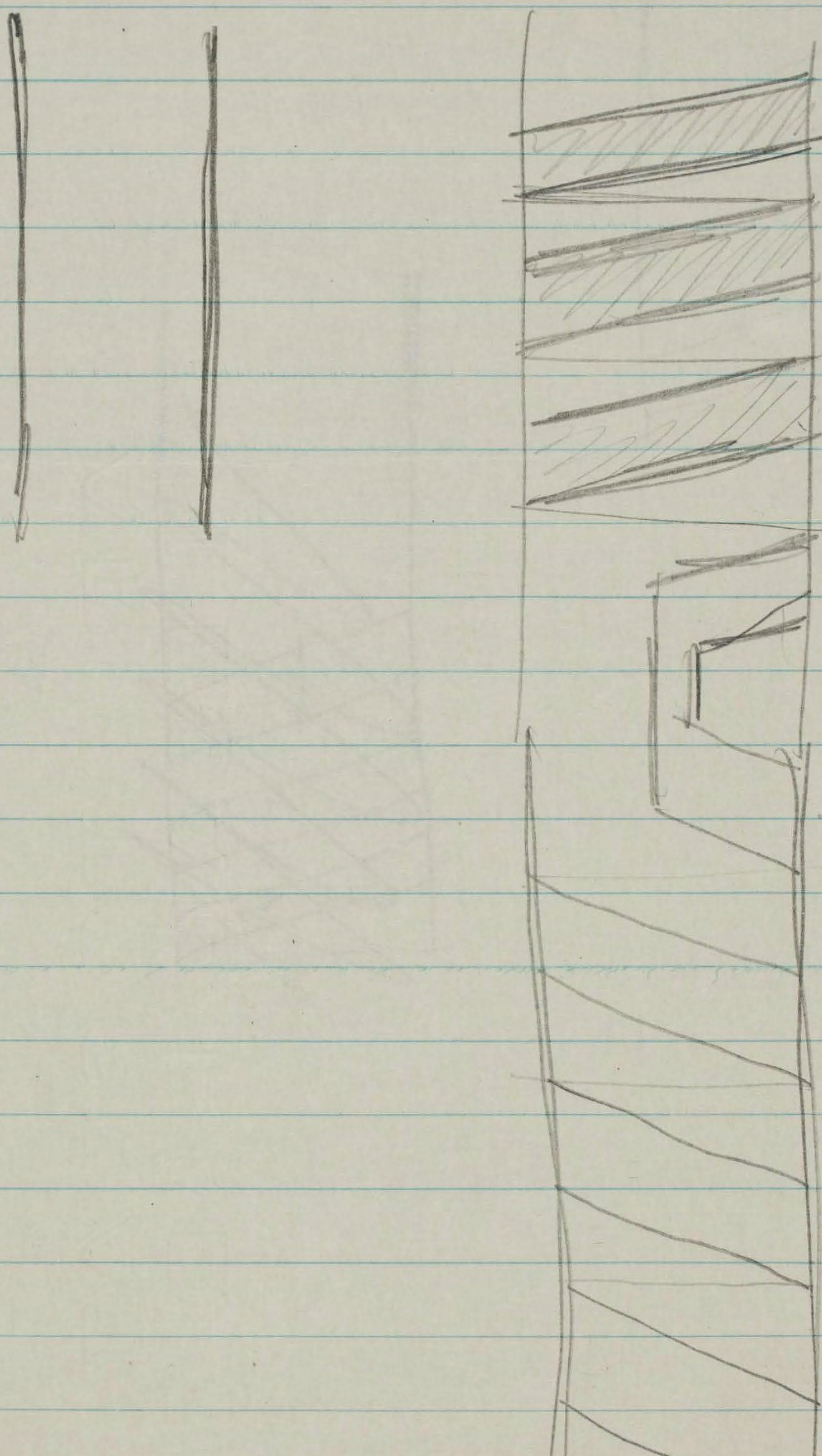
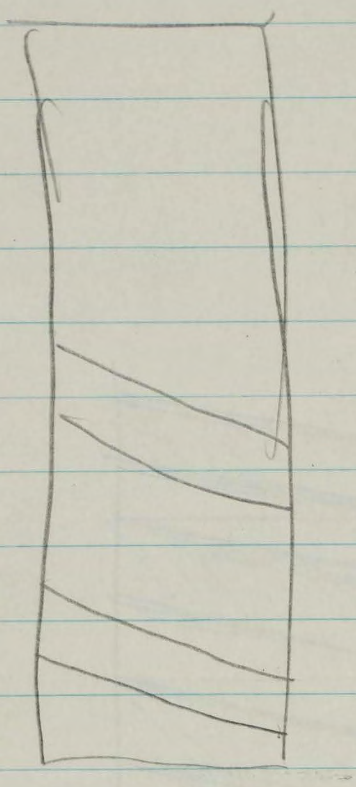
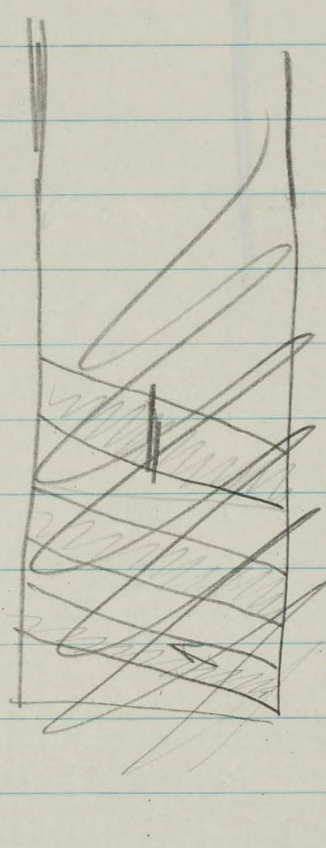
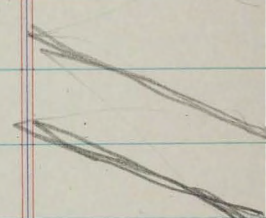
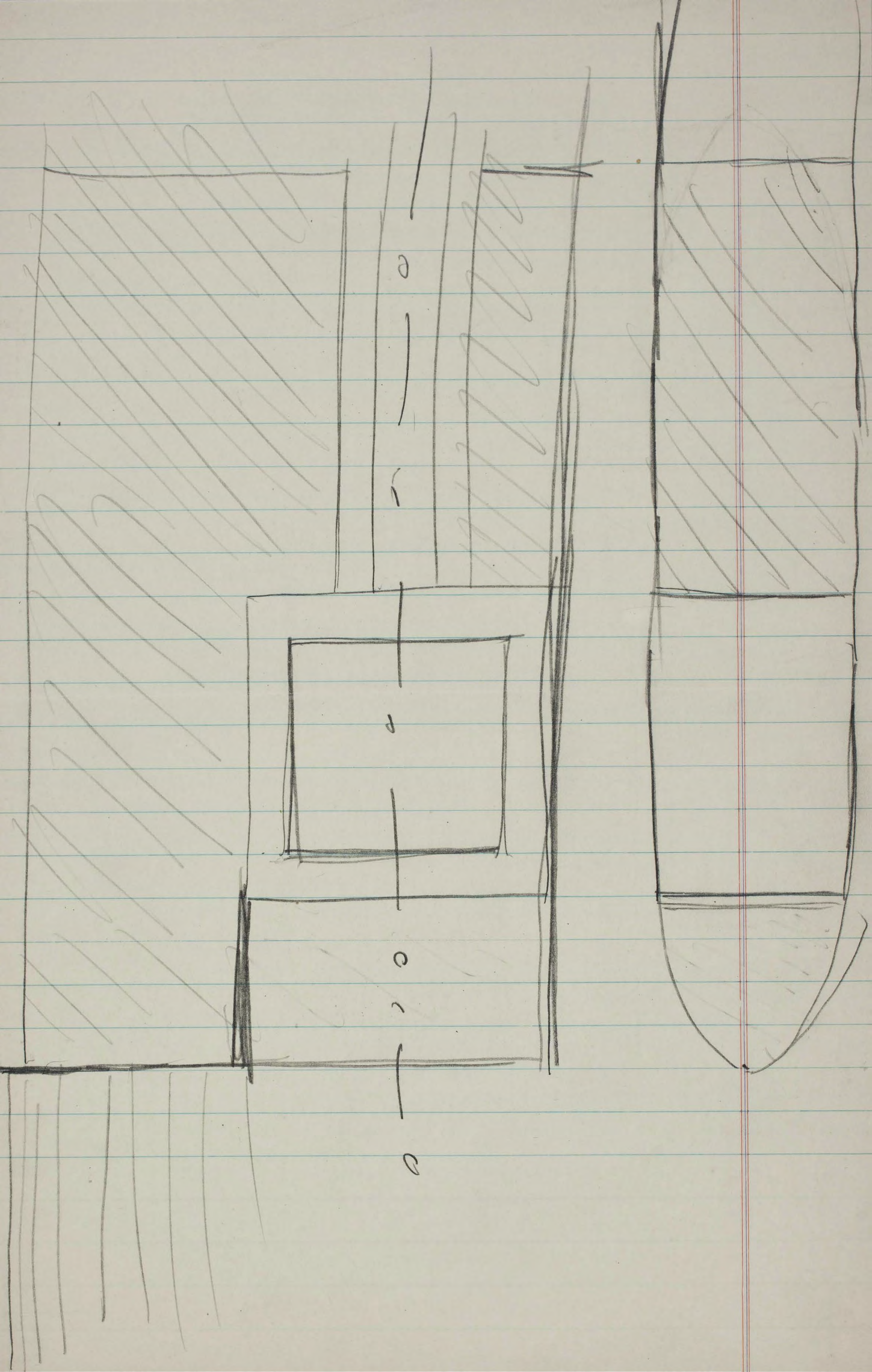


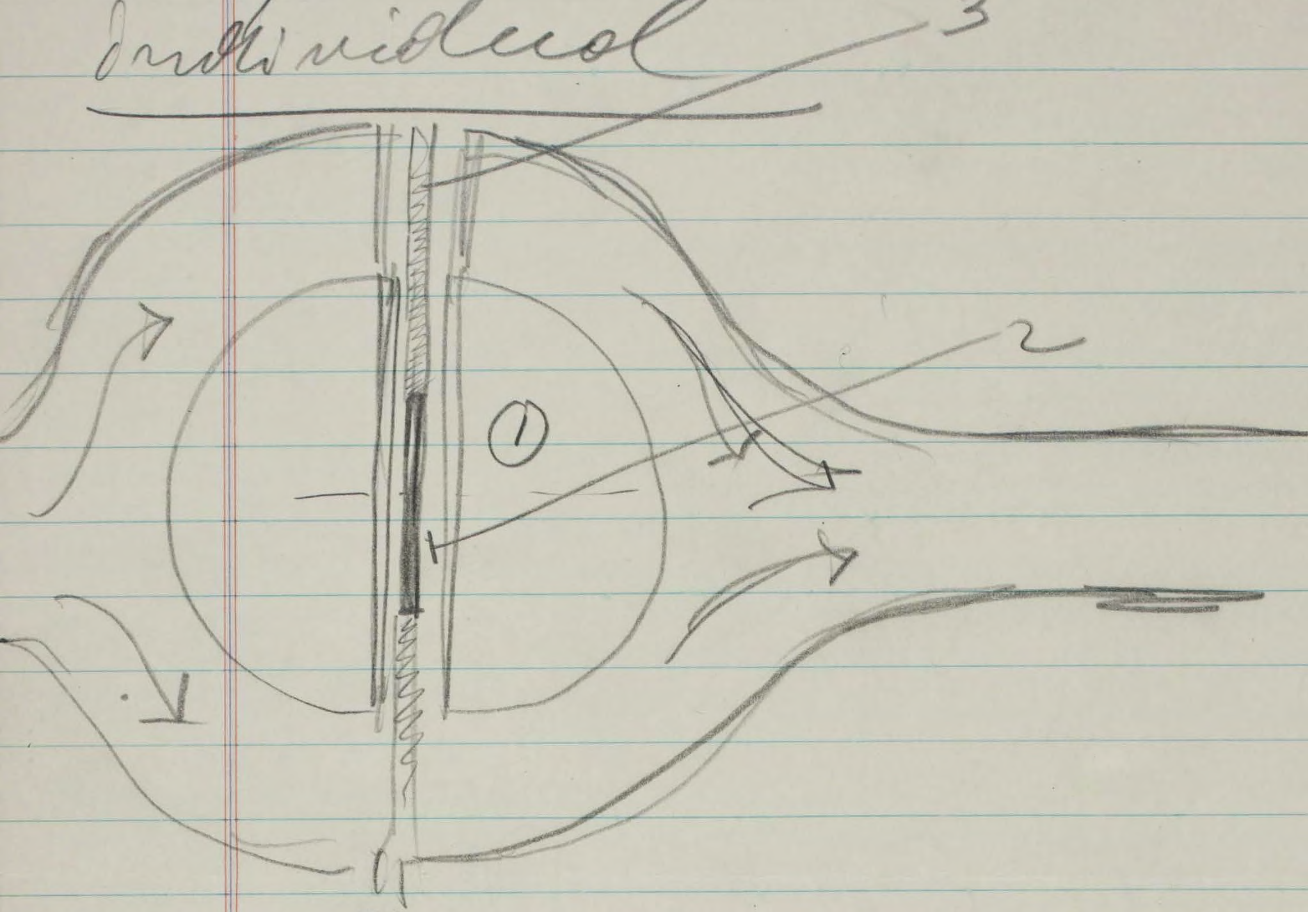


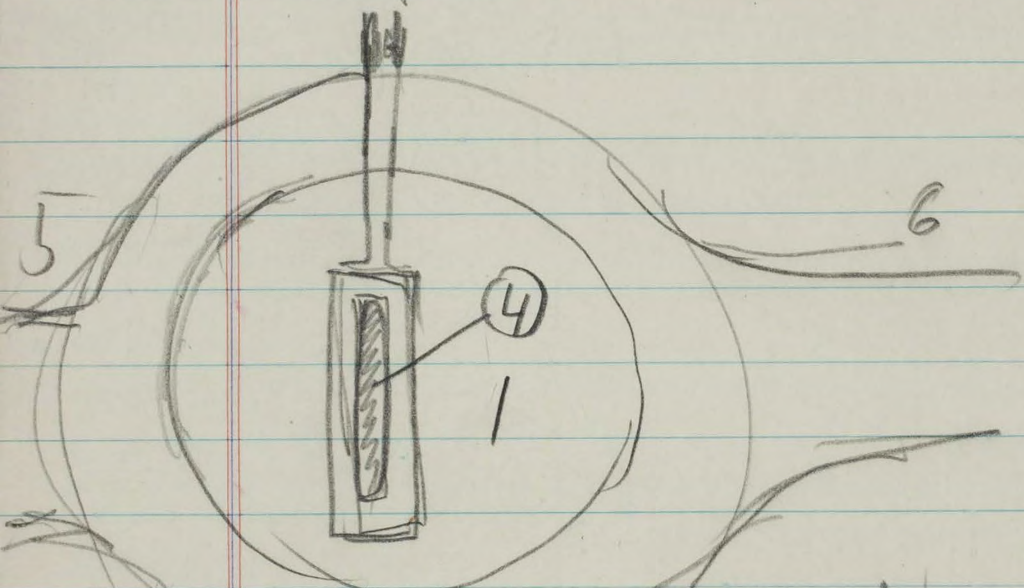


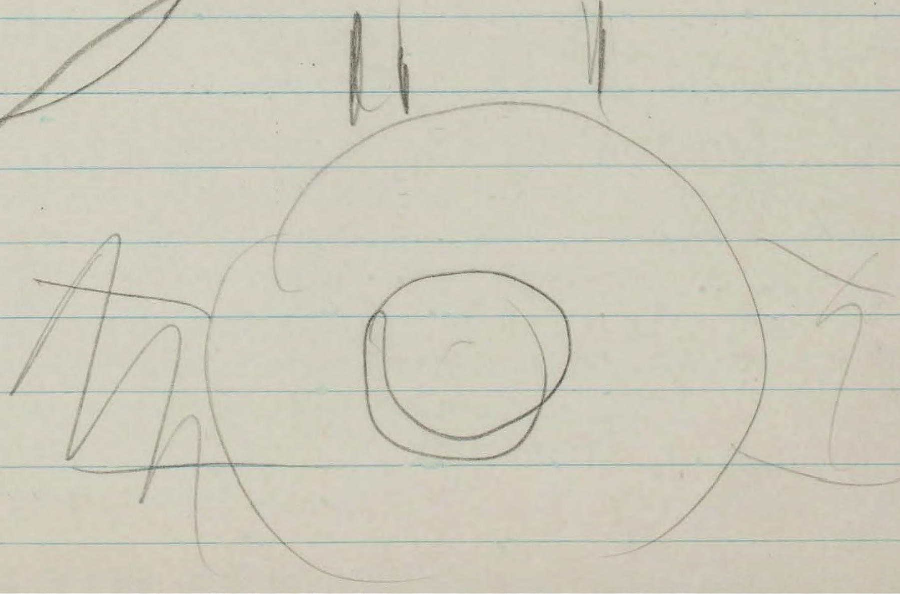




Individual







0,15 bis 0.2 gm

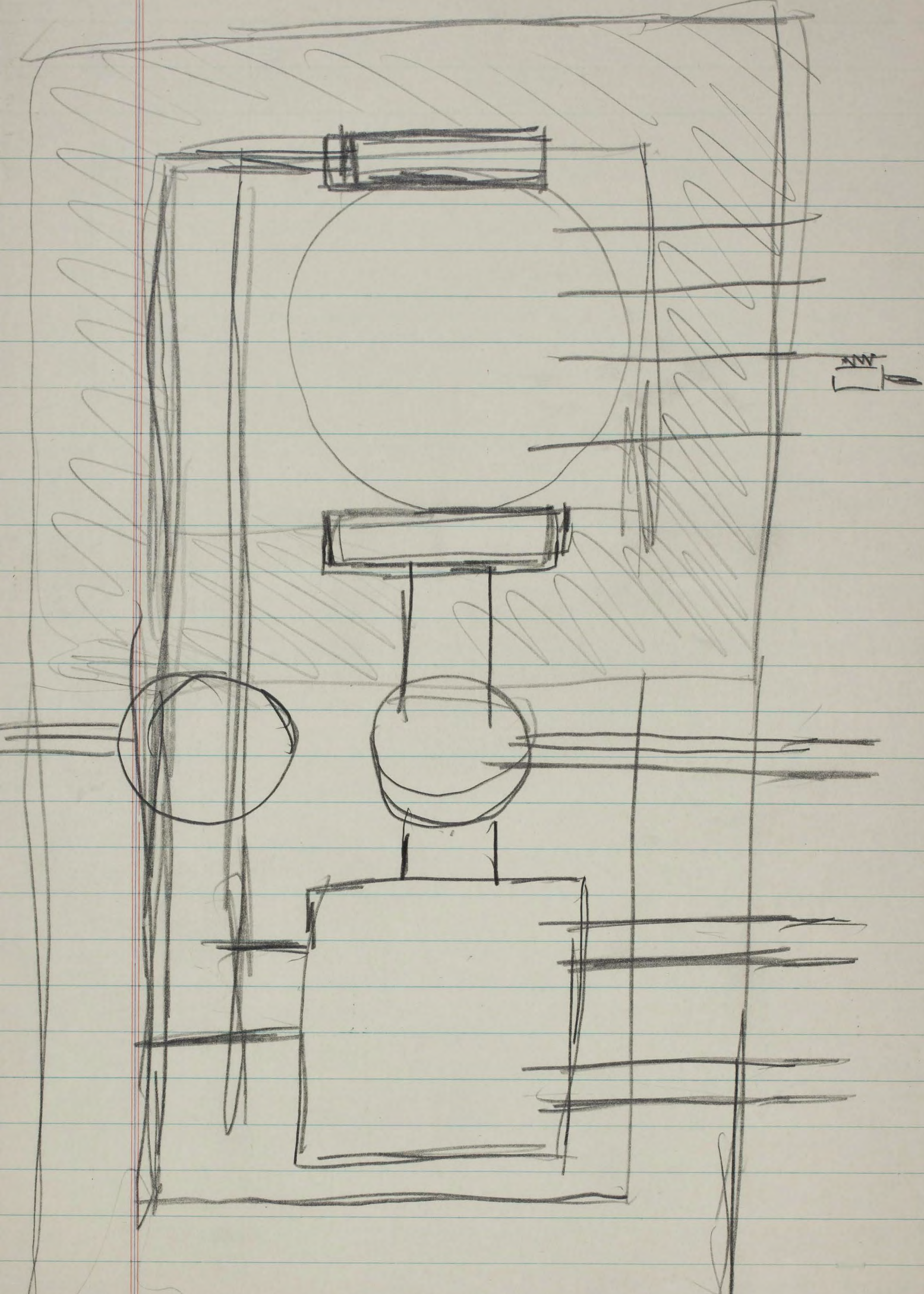
Andrographolide

in 20 cc Trombenz.

<u>10 min</u>

~~1 1/2 Alle zwei Tage~~

(2) Rona Ulay



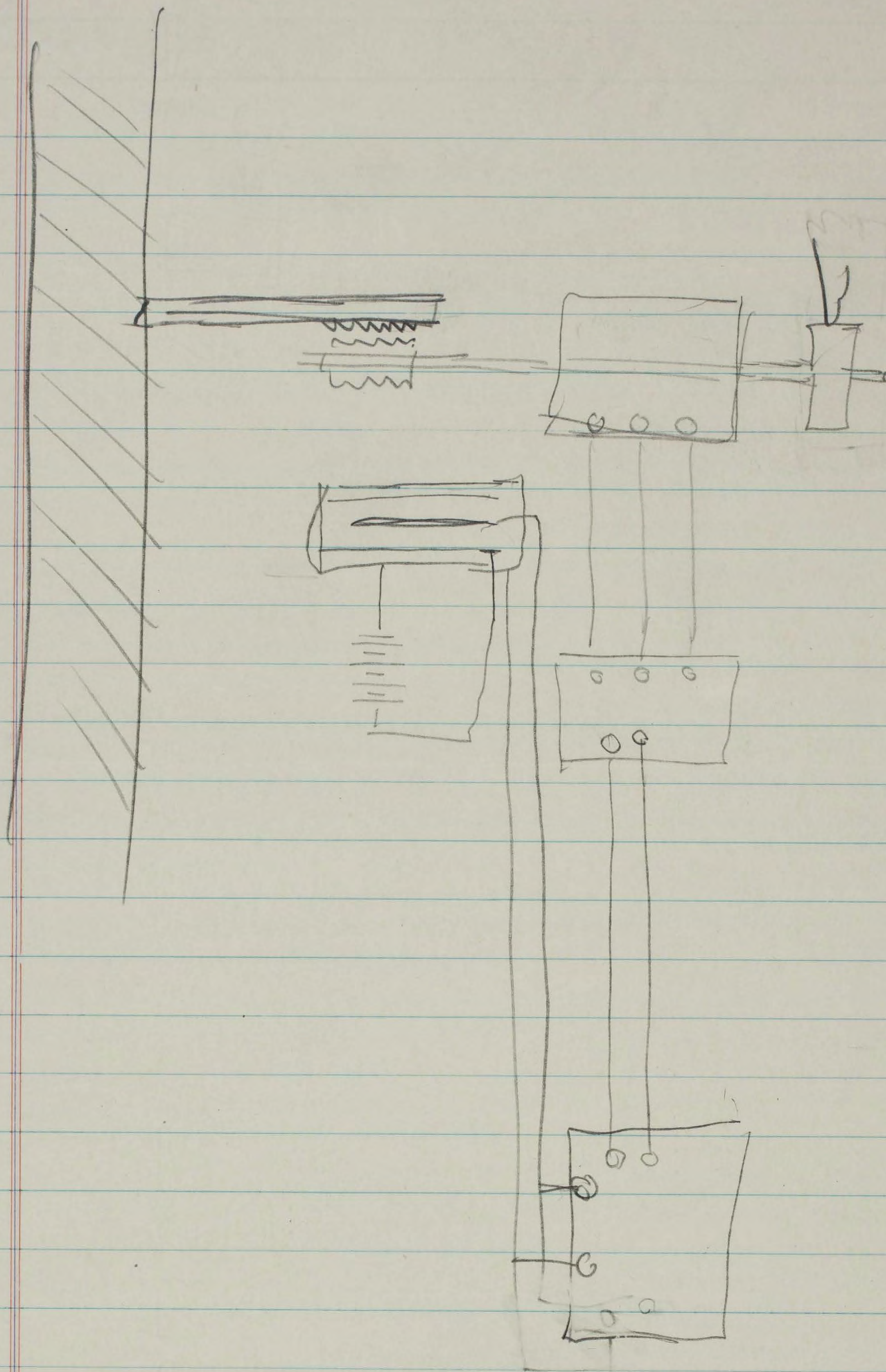
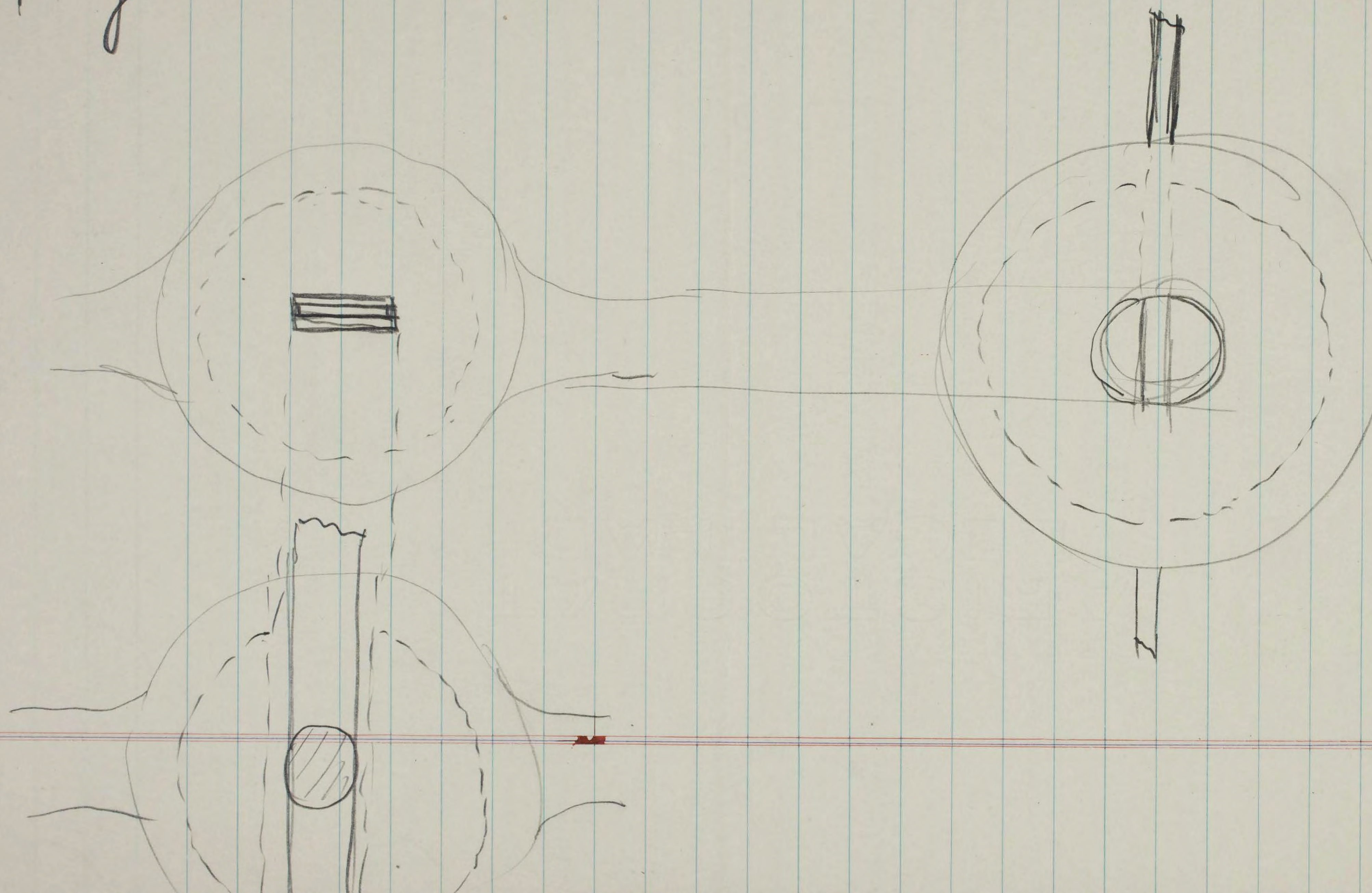


Fig. 2



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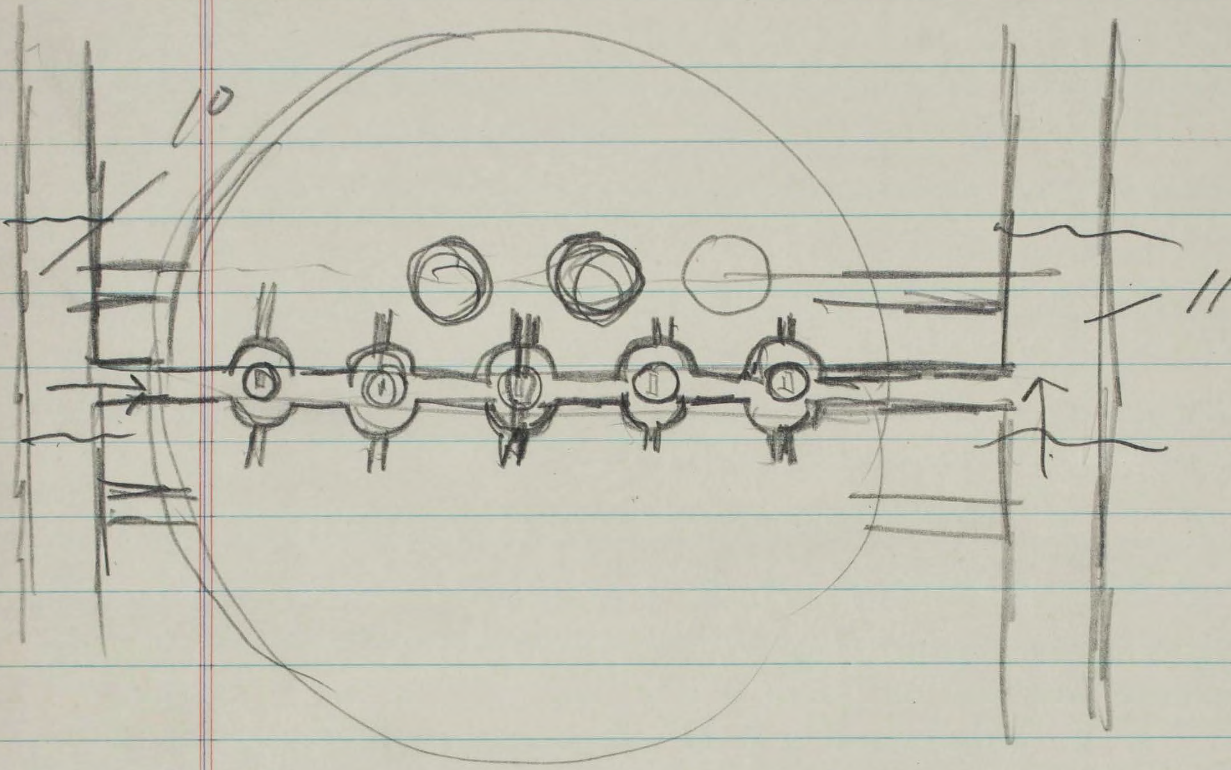

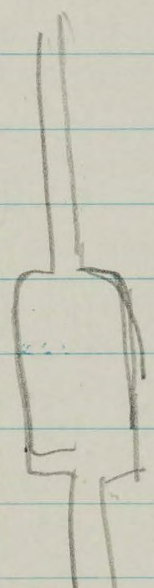

Figure 1 shows certain features of the invention. In this figure 1 is a spherical shaped body composed of uranium and carbon. The bulk of the carbon is present in the form of graphite and has a bulk density of 1.7 gms per cc. The diameter of the sphere is about meters and the weight of graphite is about 400 tons. The form and shape in which the uranium is present is described further below. The amount of uranium within the sphere is about 40 tons. A gap (2) separates the two halfs of the sphere and the sheet (3) composed of a thermal neutron absorber which is attached to a frame (4) can be moved in the horizontal direction across the gap (2). This sheet can for instance be cadmium one milimeter thick and three meters wide. The chain reaction is stopped as the frame (4) is moved to a position in which the center of the sheet (3) coincides with the center of the sphere. In order to ~~stop~~ start the chain reaction the frame (4) has to be moved so so as to move the absorbing screen (3) partly out of the gap (2) and in a certain position which is best determined empirically, the chain reaction will reach the desired intensity. The position of the absorbing screen (3) can be controlled automatically in the following way; an ionization chamber is exposed to the radiation eminating from the chain action. This ionization chamber is connected to ~~the~~ an amplifier which in turn controls an electric motor. The electric motor moves the frame (4). As the current passed by the ironization chamber increases the frame (4) is moved by the motor in such a way as to push the screen (3) further into the gap (2). If the current passed through the ironization chamber decreases below a certain value the motor is reversed and the screen (3) is thus being moved in the opposite direction. This control mechanism should have a time of response of about i.e.

In order to facilitate ... modification of the control arrangement will be shown. —

→ Insert Fig 1b

Instead of having the carbon uranium system spherically shaped one can also use other forms such as for instance, cylinder the height of which is about equal to its diameter or a cube. If such other forms are used the minimum amount of graphite which is required to make a chain action possible is larger by a factor ~~minimum~~ which is larger than unity for cylinder and cubic but ~~The amount required~~, however, ~~is~~ less than 3/2 in the case of the cylinder and less than 2 in the case of the cube.

The graphite used should be pure. However it is not necessary to use spectroscopically pure graphite which is very expensive. Graphite having an ash content of less than .05% which is commercially obtainable at a reasonable price is satisfactory provided that it contains less than one in a million part of boron by weight and less than one part in five million of the rare earth's (gadolinium,)
At the same time the ion content of the ash should be above
and the venadium content should remain below . Of course as there is less of certain impurities there could be more of others and therefore it is more precise to say that we should have

No moisture! Heating!

In order to obtain the most efficient arrangement from the point of view of the chain reaction the uranium should be present in the form of uranium metal and have a density as high as possible. If molten ~~more~~ uranium metal is used a density of about 20 gms per cc can be obtained by sintered uranium having about a density of 18 gm/cc is also satisfactory. The most efficient arrangement consists in a lattice of spheres of uranium metal. The radius of uranium sphere should be about 3 cm. We can use any of the three closed packed lattices or as a somewhat less efficient but perhaps more convenient arrangement, ~~sodium chloride lattice of the type simple~~ a cubic lattice (sodium chloride). The spacing of the uranium spheres can be ~~regulated~~ calculated for each lattice if ~~as~~ the ratio of the volumes of carbon to uranium is given. For a graphite density of about 1.7 a satisfactory ratio is 200 to 1. Somewhat less efficient from the point of view of the chain reaction but perhaps otherwise somewhat more convenient are lattices built from uranium cylinders the height of which is approximately equal with the diameter and about 5 cm and cubes 5 x 5 x 5 cms.

Figure 3 shows a somewhat different arrangement which makes it possible to use a smaller amount of uranium for maintaining the chain reaction. The uranium carbon system consists here of an outer spherical bell of about 50 cms thick which contains no uranium and an inner sphere which contains a lattice of uranium spheres. This inner sphere has a diameter of and the ratio of the volumes of graphite to uranium is about 200 to 1. Another arrangement is shown in figure 4. The uranium carbon system has here the shape of a cylinder and uranium metal cylinders which are about long and which have a radius of 2 cms are embedded in the graphite. The cross sections of these uranium metal cylinders form a lattice as is shown in figure 4b.

The rate at which the chain reaction can be maintained depends upon the efficiency of cooling. According to this invention an efficient system of transfering the heat will be obtained by using liquid bismuth. This is shown in figure 5. In figure 5 one is a steel tube having a wall of 1 mm thickness and a diameter of about 5 cms which contains uranium metal. The steel tube is surrounded by a circular gap (2) and liquid bismuth is pumped through the gap (2) along the steel cylinder. The bismuth is in direct contact with the graphite (3) which forms a wall of the gap (2). The heat which is led away by the bismuth can be transferred in a separate system which forms a boiler for water or mercury and can thus be used for the generation of power.

Figure 6 shows a somewhat different arrangement in so far as the cooling liquid is led through a pipe inside the uranium metal cylinder. If such an arrangement is used alloys of bismuth and lead having a lower melting point than bismuth may be used instead of pure bismuth. Though lead has a higher absorption for thermal neutrons than bismuth in the arrangement shown in figure 6, the bismuth lead alloy is inside the uranium cylinder and therefore at a place where the thermal neutron density is lowest. The use of bismuth alloy instead of pure bismuth has an advantage that the pipe lines leading to the uranium graphite system which carry the cooling liquid, the pumps which operate the cooling system need not be heated up to the melting point of bismuth which is about 322 centigrades but only to the melting point of the bismuth alloy.

Instead of using uranium spheres or uranium cylinders embedded in graphite it is advantageous to use uranium metal spheres of about 3 cm radius surrounded by a spherical layer of beryllum metal density between 1.5 to 2 gms per cc about 3 cm thick. Such a unit is shown in figure 7. In figure 7 one is the uranium metal sphere and 2 is the spherical layer of beryllum metal.

Similarly beryllum can be used if a lattice of uranium cylinders is used in place of a lattice of uranium spheres. This is shown in figure 8. In figure 8 (1) is a beryllum cylinder of 3 cm diameter surrounded by cylindrical layer of uranium metal 2 cm thick. This is surrounded by a gap (3) 1/2 cm wide filled with liquid bismuth and embedded in graphite (4).

[illegible]