PROJECT PHYSICS

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TRANSPARENCIES UNIT 6

Authorized Interim Version

HOLT, RINEHART & WINSTON, INC.

1809250

Harvard Project Physics

Overhead Projection Transparencies

Unit 6

T40

T40 Separation of α, β, γ Rays

Separation of α, β, γ Rays

With this transparency one may discuss the effect of a magnetic field on the emanations coming from a radioactive source. The observed deflections are presented without identification to permit the student to apply his knowledge of the behavior of charged particles in a magnetic field. (see T32 Unit 4).

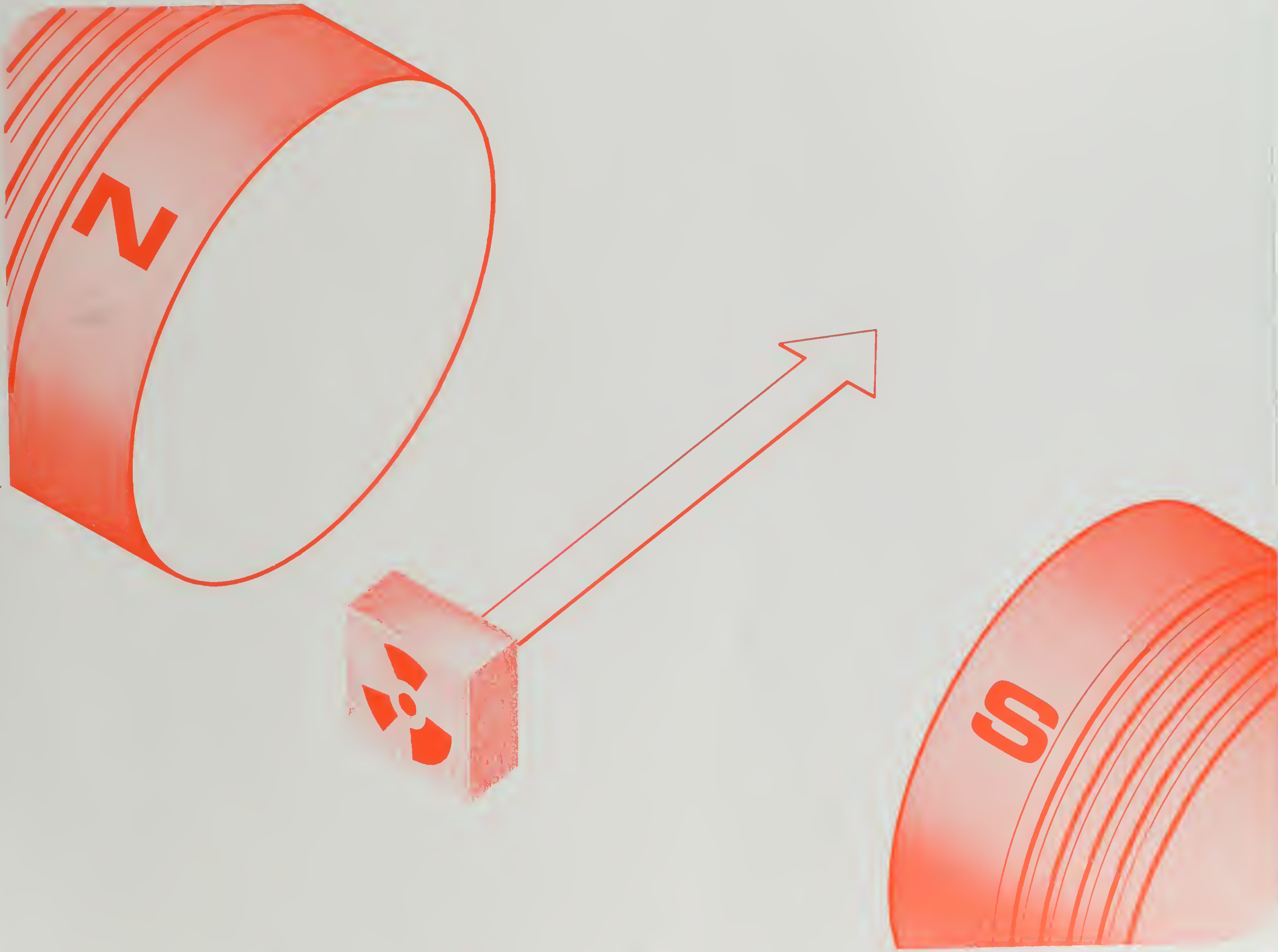
Overlay T40-A Shows an electromagnet (with current off) surrounding a lead-shielded source of radio-activity. When no magnetic field is present only one path of radiation is observed. Introduce overlay T40-B.

Overlay T40-B Shows the effect of a moderate magnetic field strength on the emanations. Since a deflection occurs, it must be true that this emanation possesses charge. Ask students to apply the right hand and left hand rules to determine the charge on this ray. It will be seen that the left hand rule is applicable since the force is upward and consequently the charge is negative. It is, of course, the β ray.

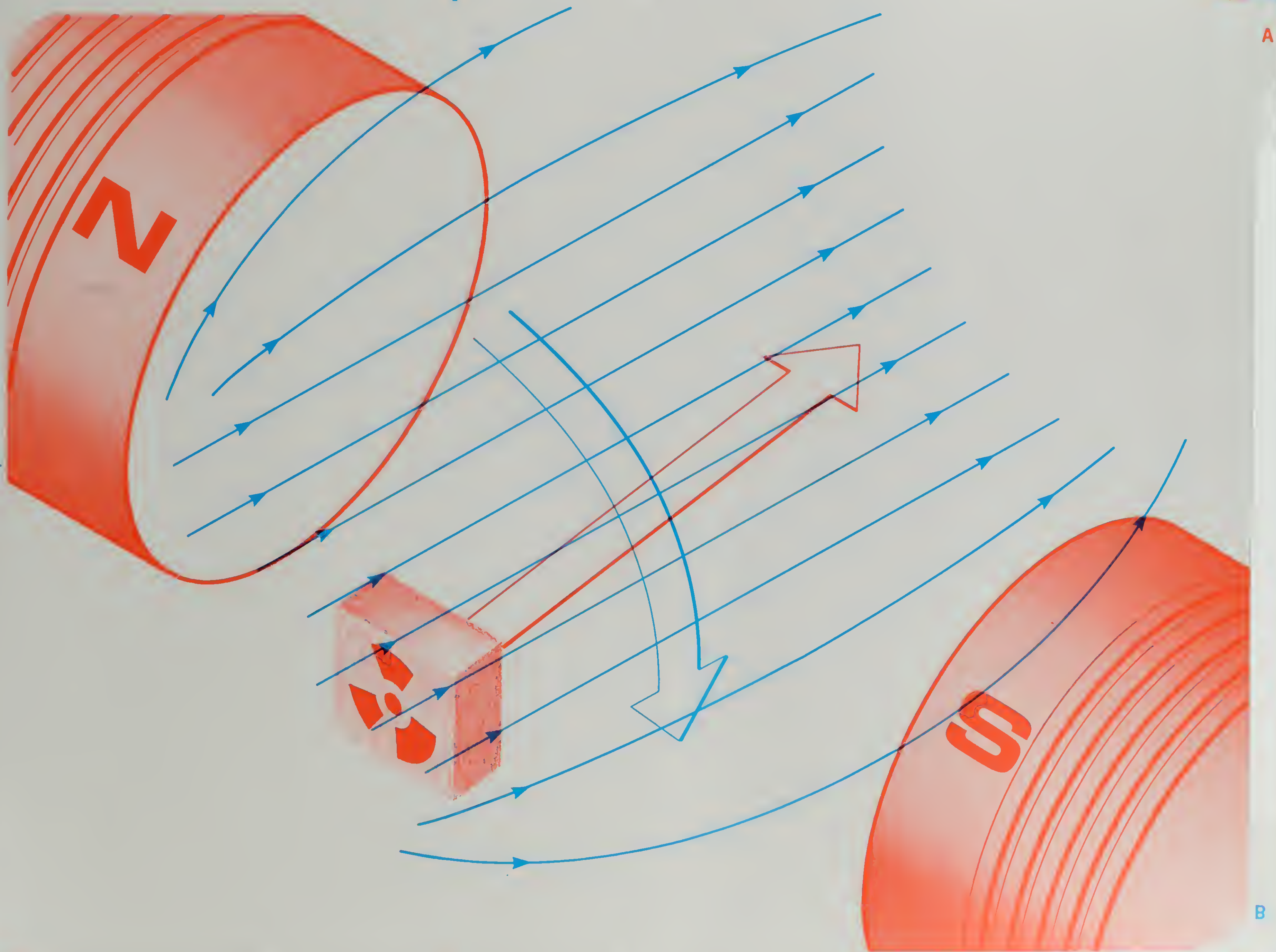
Note: Beta rays exhibit a continuous distribution of energies. We have indicated betas of only one energy here for simplicity.

Remove overlay T40-B and introduce overlay T40-C.

Overlay T40-C Shows the effect of a more intense magnetic field on the radioactive emanations. A new deflection is noted which necessarily is positive since it is opposite to the deflections of the β rays. The degree of deflection shows that this positive ray, the α ray, has a much larger momentum than that of the β's. Point out that the decrease in the radius of the β's is a result of the increased $\vec{B}$ field. Additionally, have students comment on the undeflected ray. Indicate that further increases in the magnetic field strength will not affect this ray, although the other two would continue to be affected. This undeflected ray is, of course, the neutral γ ray.


N
S

A

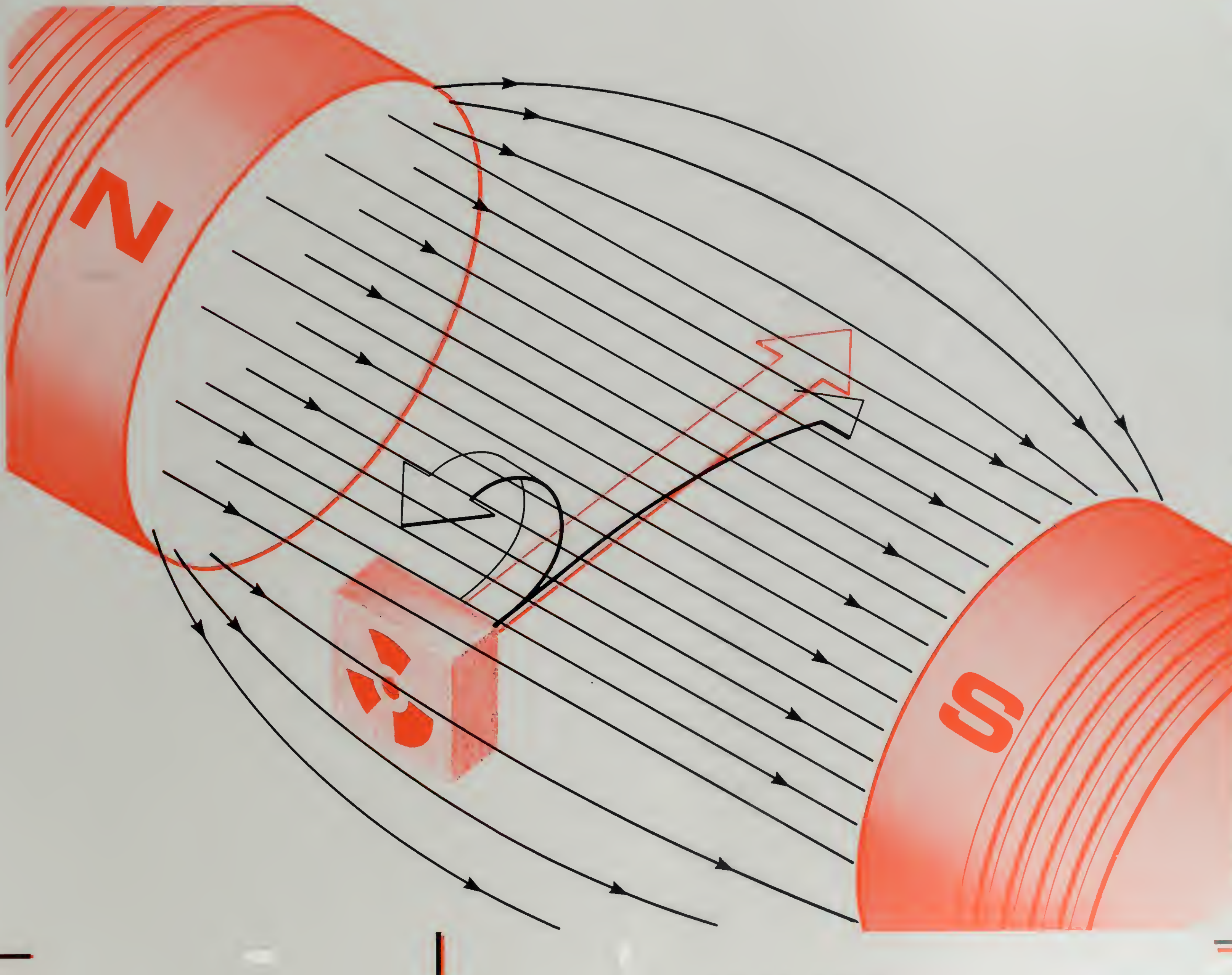


B

T-40

A

C



T41

T41 Rutherford's α-Particle "Mousetrap"

Rutherford's α-Particle "Mousetrap"

This transparency presents a simplified detail of the apparatus used by Rutherford and Royds in 1909 to show that the α particle is a doubly-ionized helium atom, that is, the nucleus of a He atom.

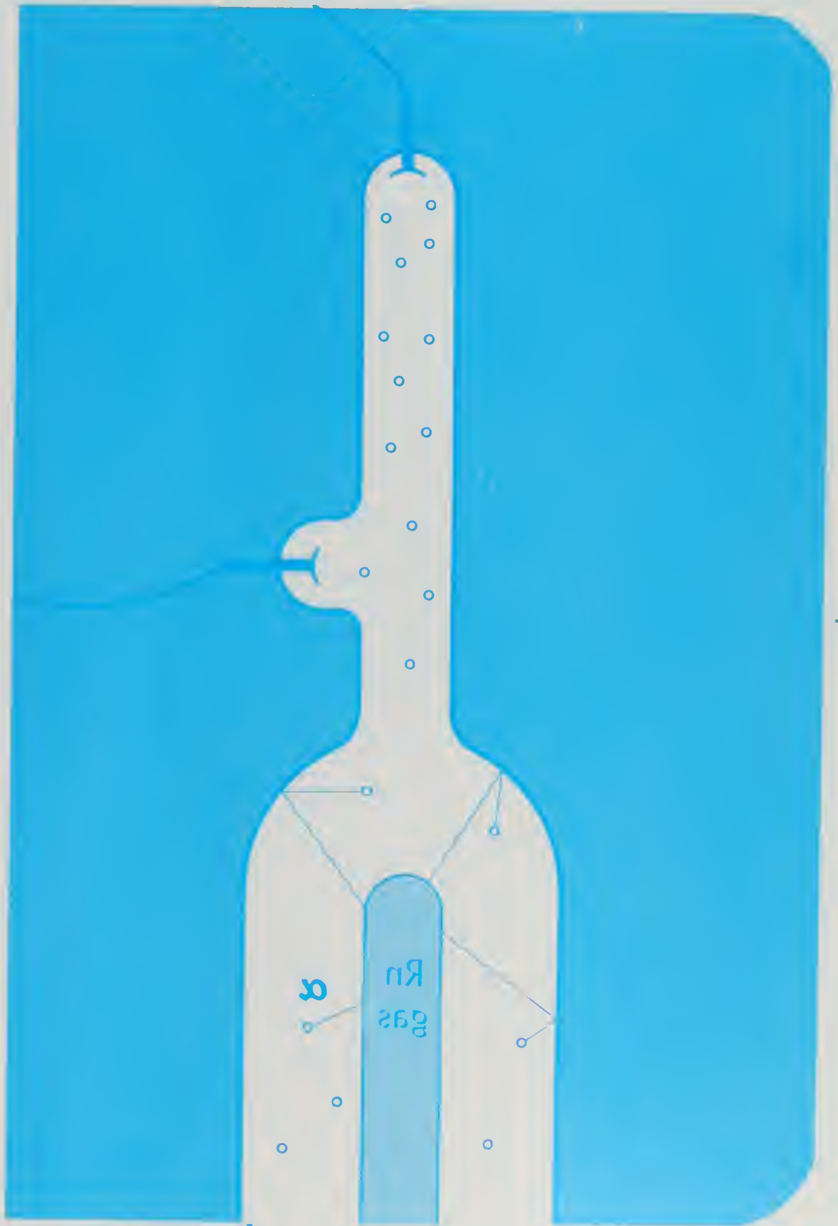
Overlay T41-A Shows a thick-walled glass chamber leading to a discharge tube at the top. In the lower portion is a thin-walled tube one hundreth of a millimeter thick containing radon gas. The outer tube was evacuated and the apparatus was allowed to stand for a week. As time passed, α particles from the radon gas traveled through the thin-walled tube into the evacuated chamber. Here the "α particle gas" was compressed into the discharge tube by means of a mercury column not shown. A potential difference was maintained across the electrodes and an electric discharge was produced in the "gas". The resulting light was examined with a spectroscope. Introduce overlay T41-B with a mask.

Overlay T41-B Illustrates more α particles in the discharge tube and suggests light emanating from the tube. The right side of the overlay provides the spectra which were observed as time went on. Reveal each spectrum separately by sliding an opaque mask down the overlay. The final spectrum is a comparison spectrum of helium. Discuss the interpretation of these results.

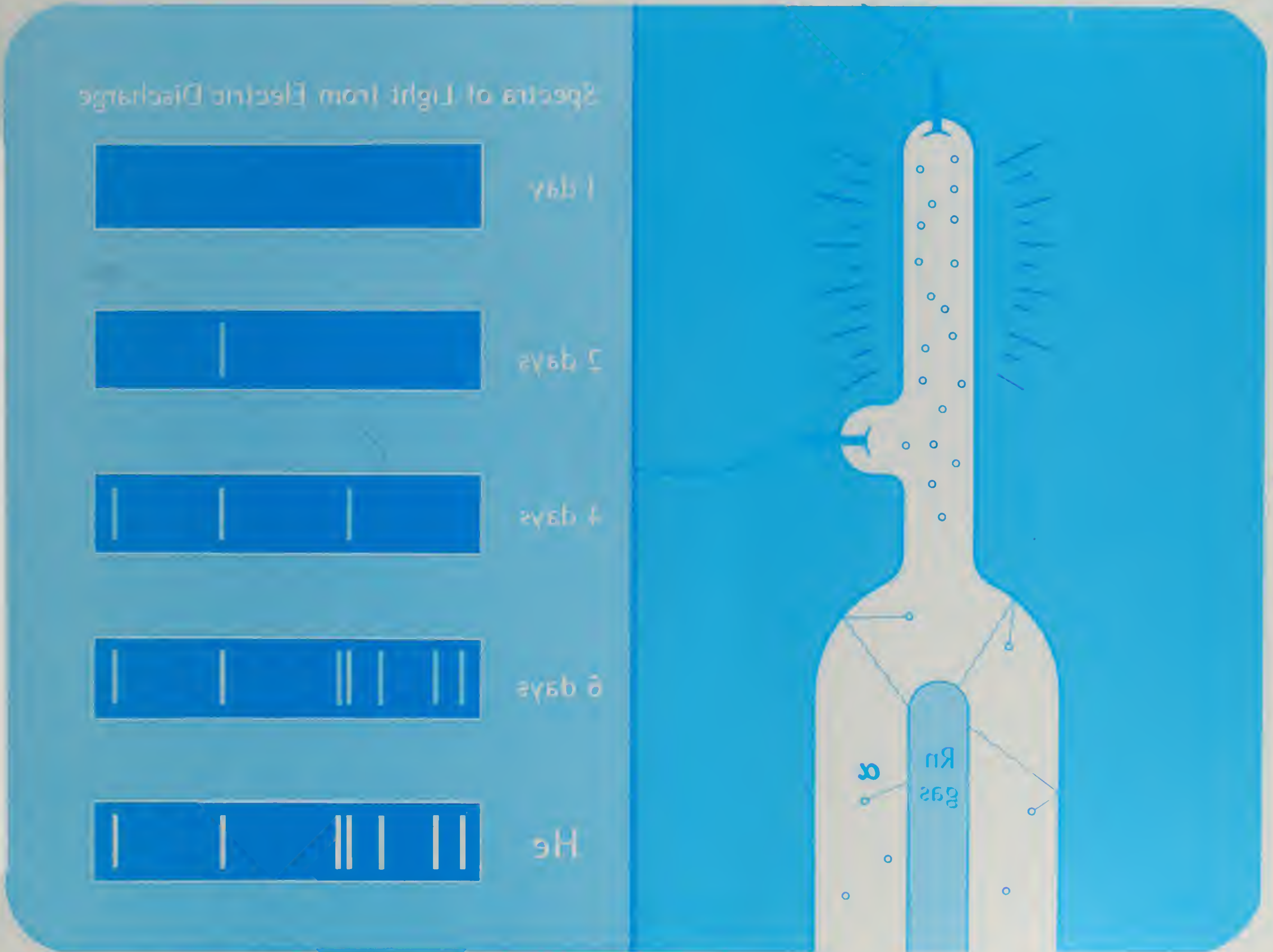
Note: You may wish to add the actual colors to the spectral lines. This can be done with colored wax pencils, felt markers, or colored tapes. Refer to T39 Unit 4 for exact coloration.

T-41

A



T-41 T-41



Spectra of Light from Electric Discharge
1 day
2 days
4 days
6 days
He
α
Rn
gas

T42 Radioactive Disintegration Series

T42

This transparency will be useful in discussing the process of radioactive transmutation which elements undergo by emitting α and β particles. Four series are presented: Uranium-Radium; Thorium; Actinium; Neptunium. It is intended that this transparency be completed by the teacher (with a wax pencil) as students consult the Periodic Table and determine the complete symbol with A and Z for each member of the series.

Overlay T42-A Shows the principal components in the Uranium Series. U-238 emits an α particle resulting in an element possessing 90 protons and 234 nucleons. Element 90 is Thorium. Therefore, the symbol ${}_{90}Th^{234}$ is placed in the first blank circle. Th-234 then emits a β particle resulting in an element with 91 protons and 234 nucleons. According to the Periodic Table element 91 is Protactinium; therefore, ${}_{91}Pa^{234}$ is placed in the second circle. The procedure continues in a similar manner until the stable daughter is reached.

In this series some points are reached by a process called "branching"; a small fraction of atoms decay in a manner other than that shown. The branching in this series is as follows:

$Th^{234} \xrightarrow{\beta} Pa^{234} \xrightarrow{\beta} U^{234}$

$Bi^{214} \xrightarrow{\alpha} Tl^{210} \xrightarrow{\beta} Pb^{210} \xrightarrow{\beta} Bi^{210}$

Remove overlay T42-A and introduce overlay T42-B.

Overlay T42-B Shows the scheme for the Thorium Series. Follow the same procedure as in overlay T42-A. The branching in this series is as follows:

$Po^{216} \xrightarrow{\beta} At^{216} \xrightarrow{\alpha} Bi^{212}$

$Bi^{212} \xrightarrow{\beta} Po^{212} \xrightarrow{\alpha} Pb^{208}$

Remove overlay T42-B and introduce overlay T42-C.

Overlay T42-C Shows the scheme for the Actinium Series, so-called because U-235 was once known as Actinouranium. The branching in this series is as follows:

$Ac^{227} \xrightarrow{\beta} Th^{227} \xrightarrow{\alpha} Ra^{223}$

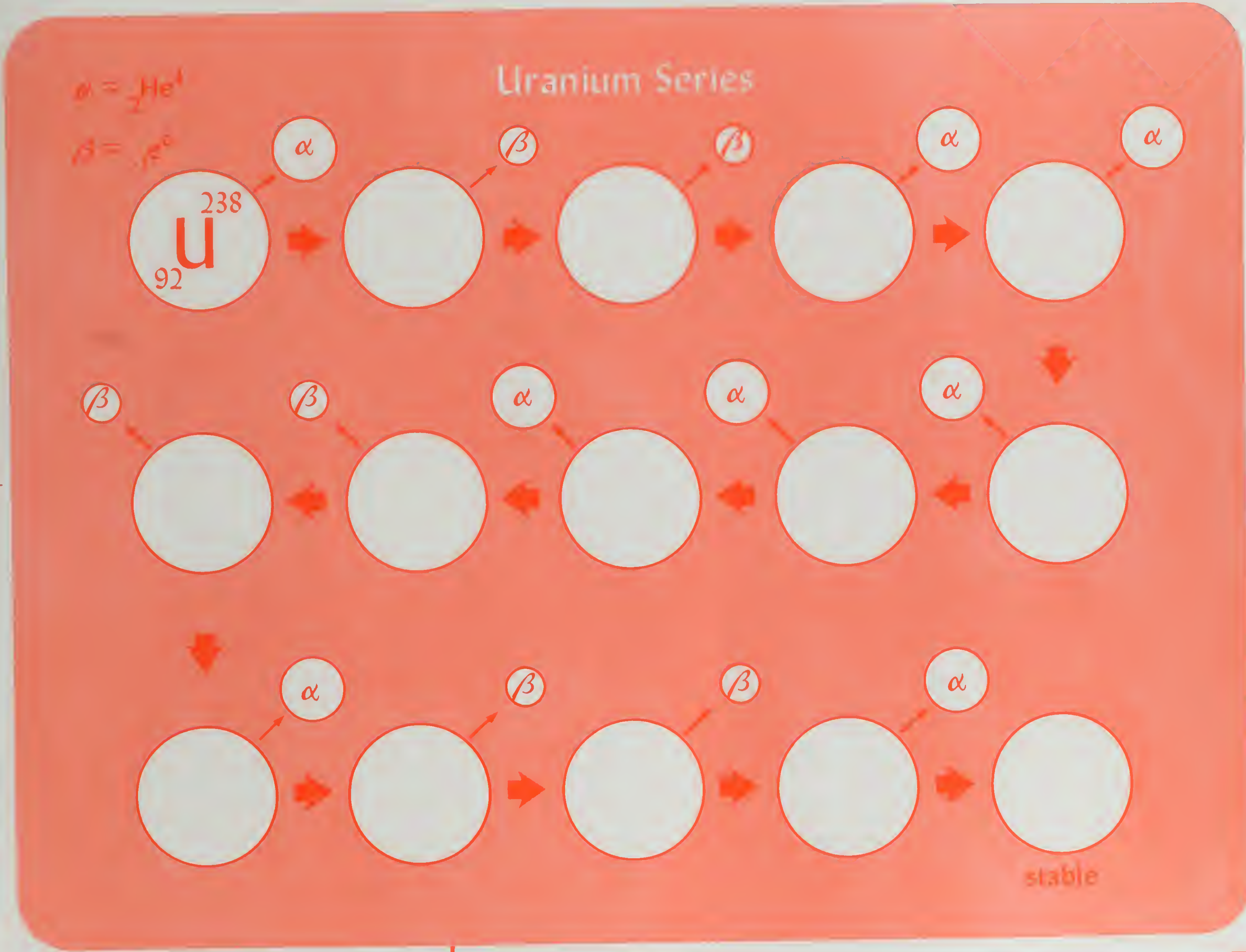
$Po^{215} \xrightarrow{\beta} At^{215} \xrightarrow{\alpha} Bi^{211} \xrightarrow{\beta} Po^{211} \xrightarrow{\alpha} Pb^{207}$

Remove overlay T42-C and introduce overlay T42-D.

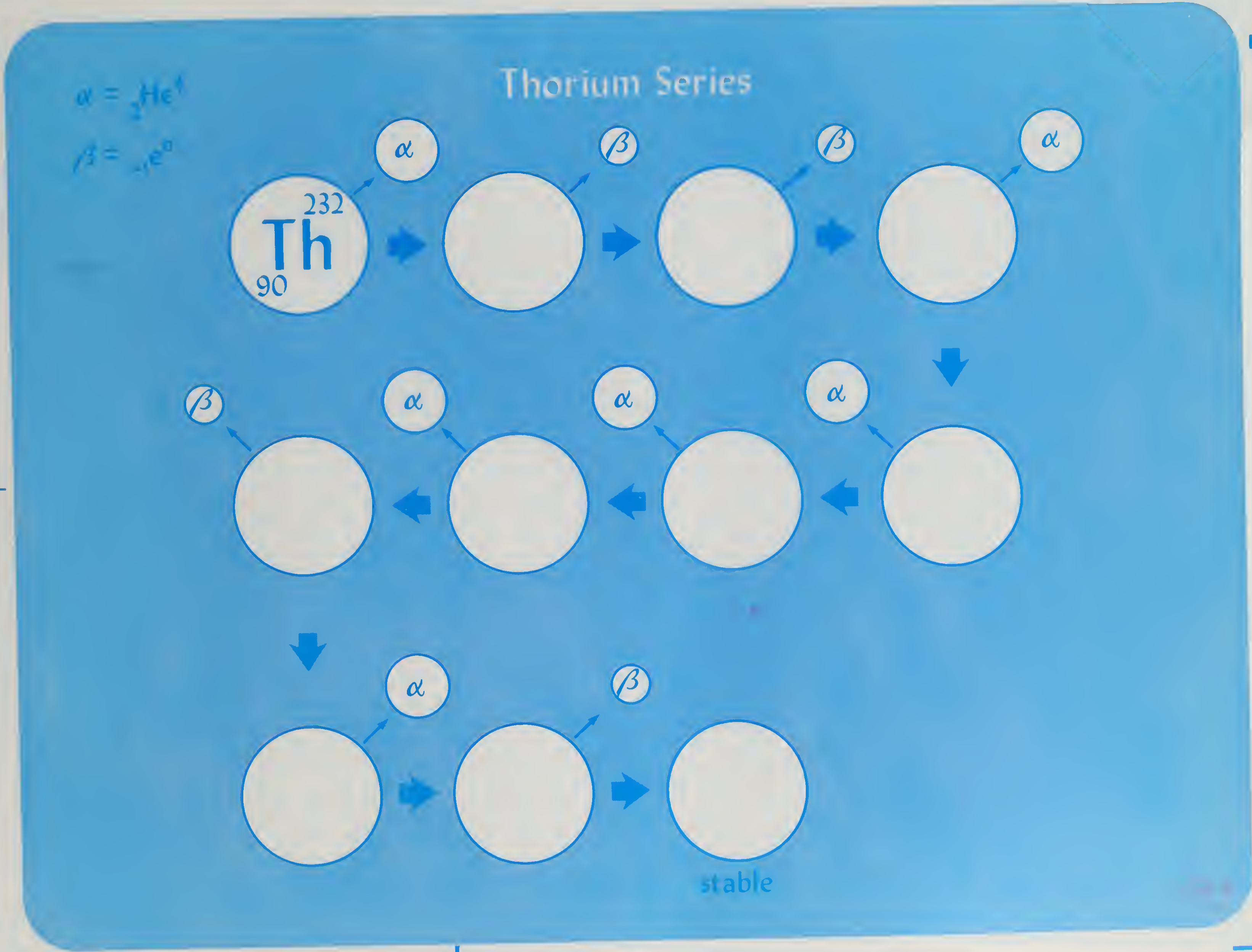
Overlay T42-D Shows the scheme for the Neptunium series. The branching is as follows:

$Bi^{213} \xrightarrow{\alpha} Tl^{209} \xrightarrow{\beta} Pb^{209}$

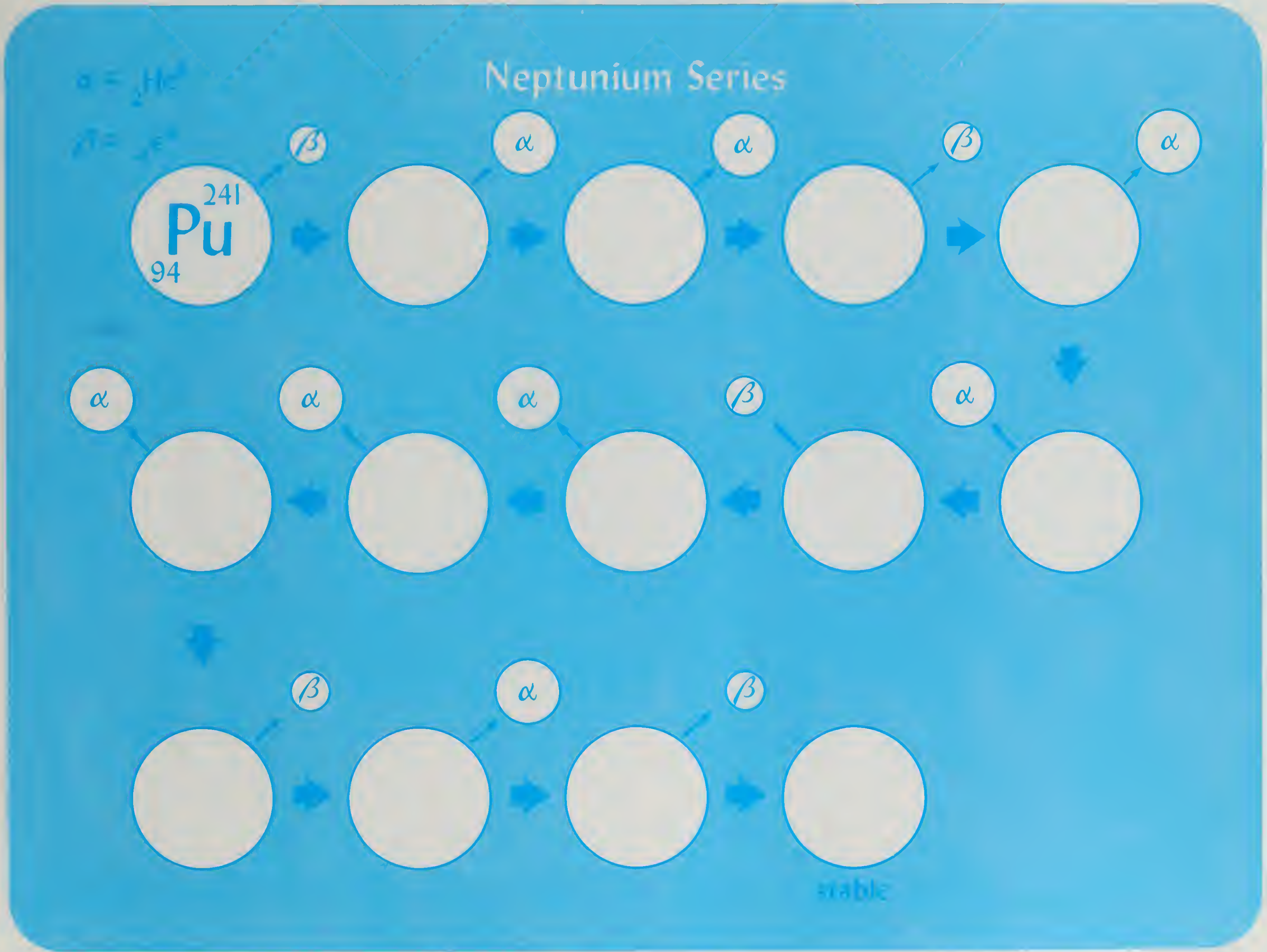
A



Uranium Series
$\alpha = {}_2He^4$
$\beta = {}_{-1}e^0$
$^{238}_{92}U$
α
β
β
α
α
β
β
α
α
α
α
β
β
α
stable


Thorium Series
$\alpha = {}_2He^4$
$\beta = {}_{-1}e^0$
232
Th
90
α
β
β
α
α
α
α
β
α
β
stable

C


Neptunium Series
241
Pu
94
β
α
α
β
α
α
α
α
β
α
β
α
β
stable

T43 Radioactive Decay Curve

T43

T43 Radioactive Decay Curve

Use this transparency to aid in the discussion of the half-life concept in radioactive decay. A number of overlays displaying sample data for a radioactive element and its accumulating "daughter" atoms are presented for analysis.

Overlay T43-A Shows the axes on which data for surviving and accumulating atoms will be plotted. The vertical axis represents numbers of atoms, N_0 being the original quantity. The horizontal axis is in arbitrary time units. Introduce overlay T43-B.

Overlay T43-B Shows plotted data for the surviving parent atoms and the accumulating daughter atoms for a short time interval. Point out that as radioactive decay occurs, the original radioactive atoms transmute into new, in this case stable, atoms. The plot shows this increasing number of daughter atoms along with the remaining number of parent atoms. Add overlay T43-C.

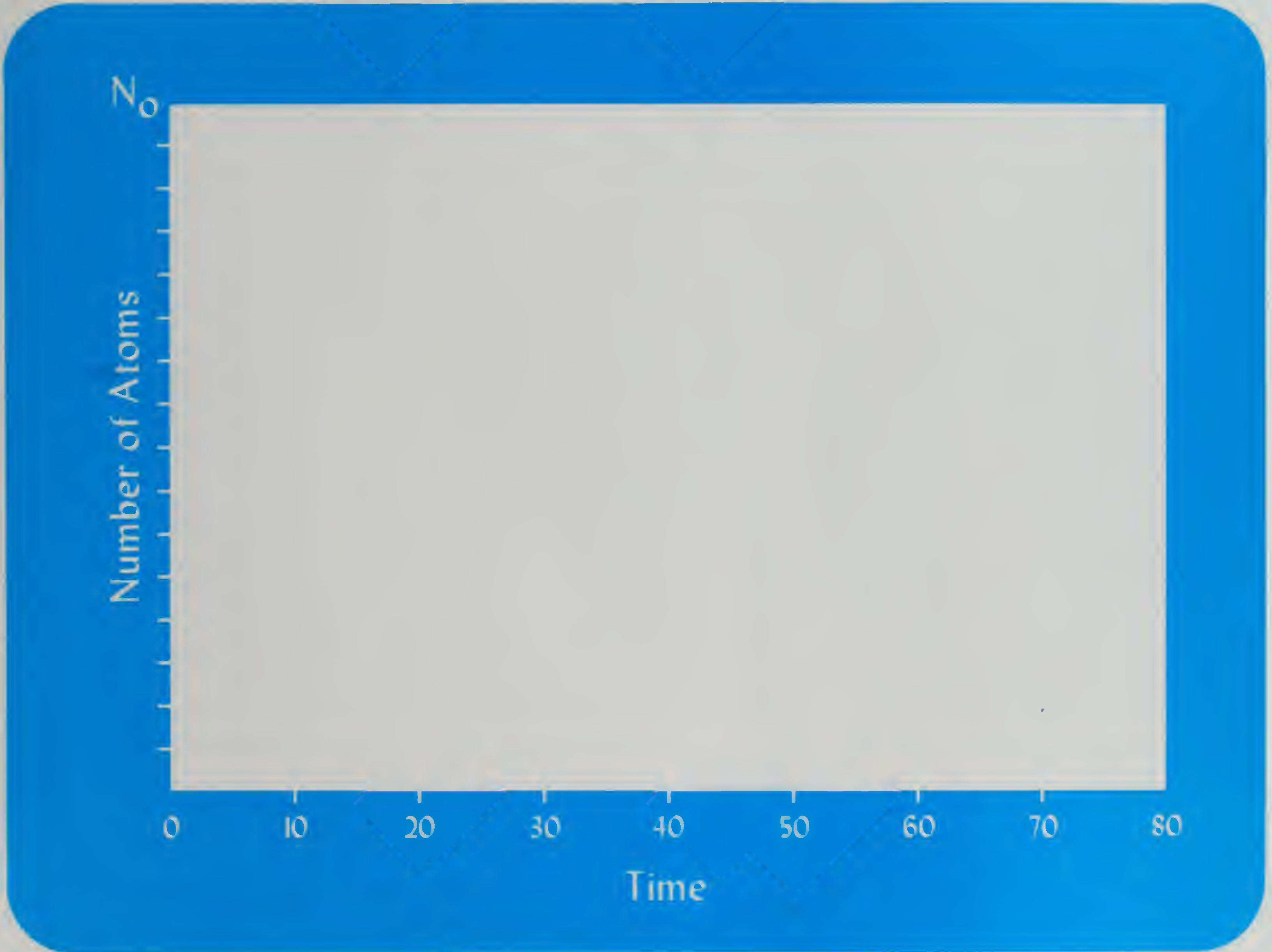
Overlay T43-C As time goes on, more parent atoms decay into new daughter atoms. This overlay shows that the number of daughter atoms eventually becomes equal to the number of remaining parent atoms. Add overlay T43-D.

Overlay T43-D to Overlay T43-F As time progresses, the number of daughter atoms is seen to increase further while the number of surviving parent atoms is shown decreasing. Continue with the remainder of the overlays.

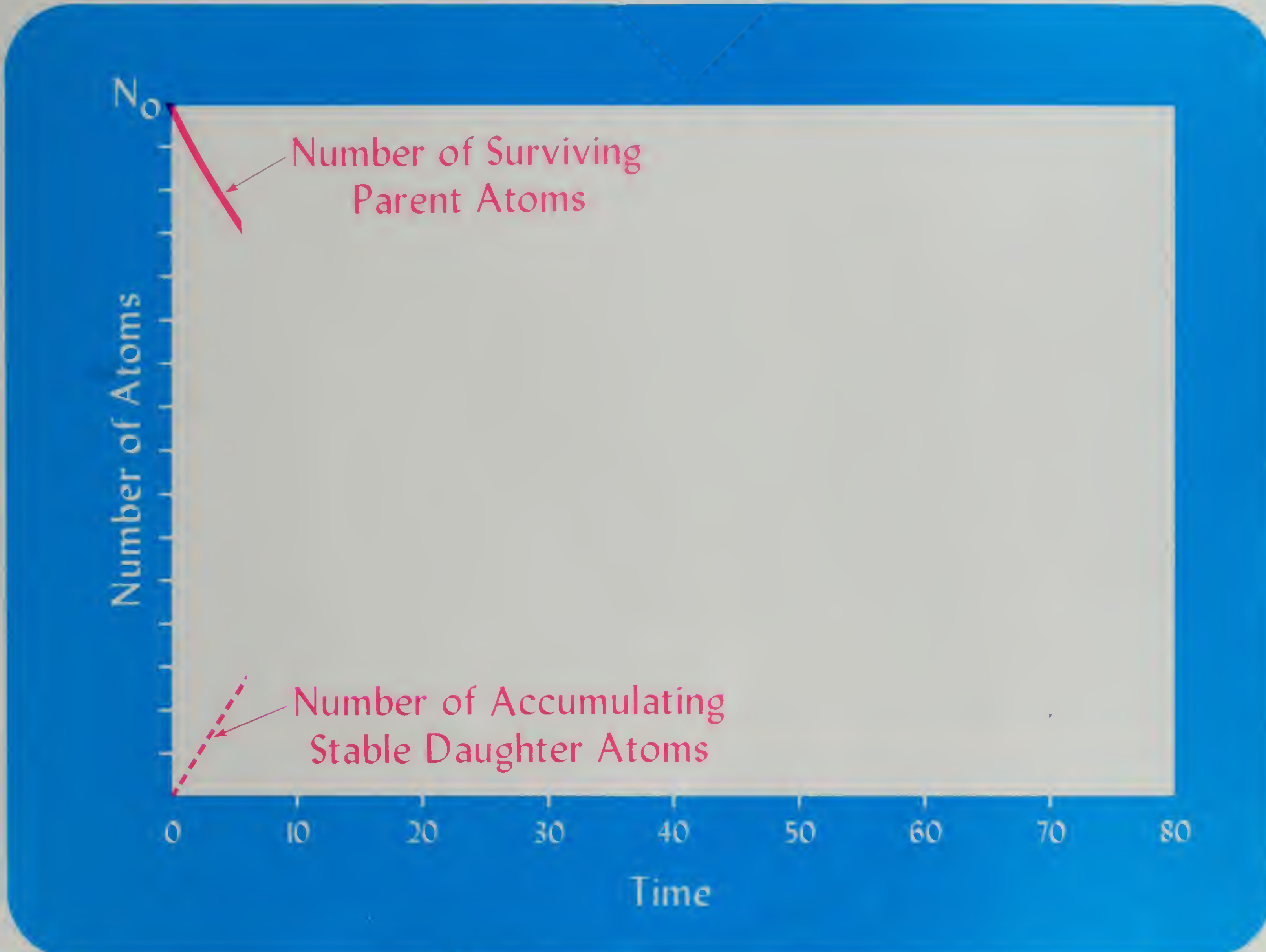
Now that you have presented the complete data for the graph you can indicate the suggestion of Rutherford that it is possible to specify the time required for any particular fraction of a radioactive substance to decay to one-half, one-third, or one-fourth of the original quantity. The fraction $\frac{1}{2}$ has been chosen for convenience and the time T thus required is called the **half-life.** It is the time during which a radioactive material decays to one-half of its original amount.

Ask students to point out the half-life from the graph. It is 20 time units. Remove overlays T43-F-E-D and show that the number of atoms remaining after 20 time units have elapsed is $N_0/2$. Return T43-D and show that at the end of another 20 units of time (one half-life) the number of atoms remaining is $\frac{1}{2}$ the original $[\frac{1}{2}(N_0/2) = \frac{1}{4} N_0]$. Return overlay T43-E and show that after another half-life (20 time units) the number of atoms is $\frac{1}{2}$ the original $[\frac{1}{2}(\frac{1}{4} N_0) = \frac{1}{8} N_0]$. Finally show that overlay T43-F illustrates another half-life $[\frac{1}{2}(\frac{1}{8} N_0) = 1/16\ N_0]$.

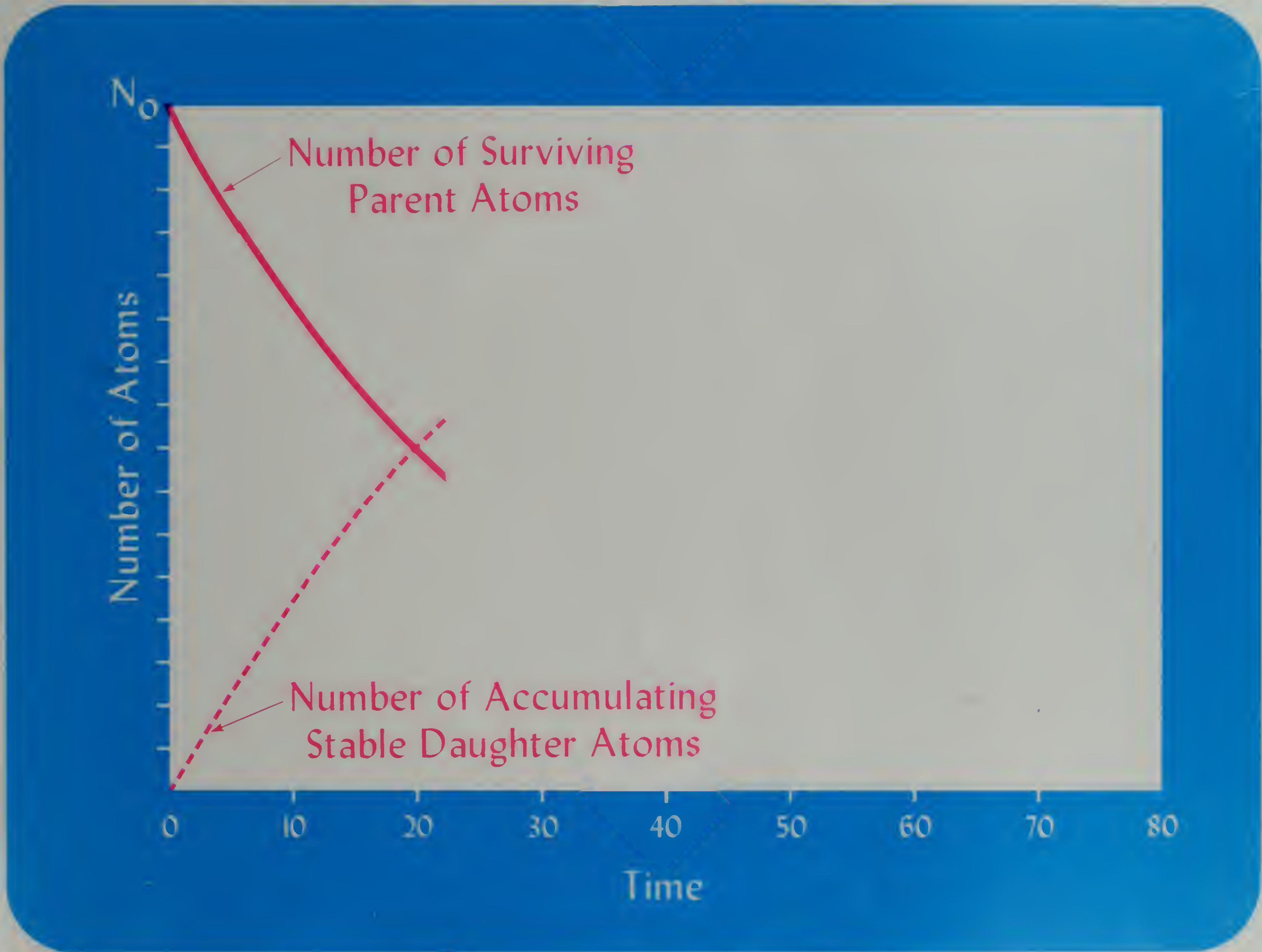
A



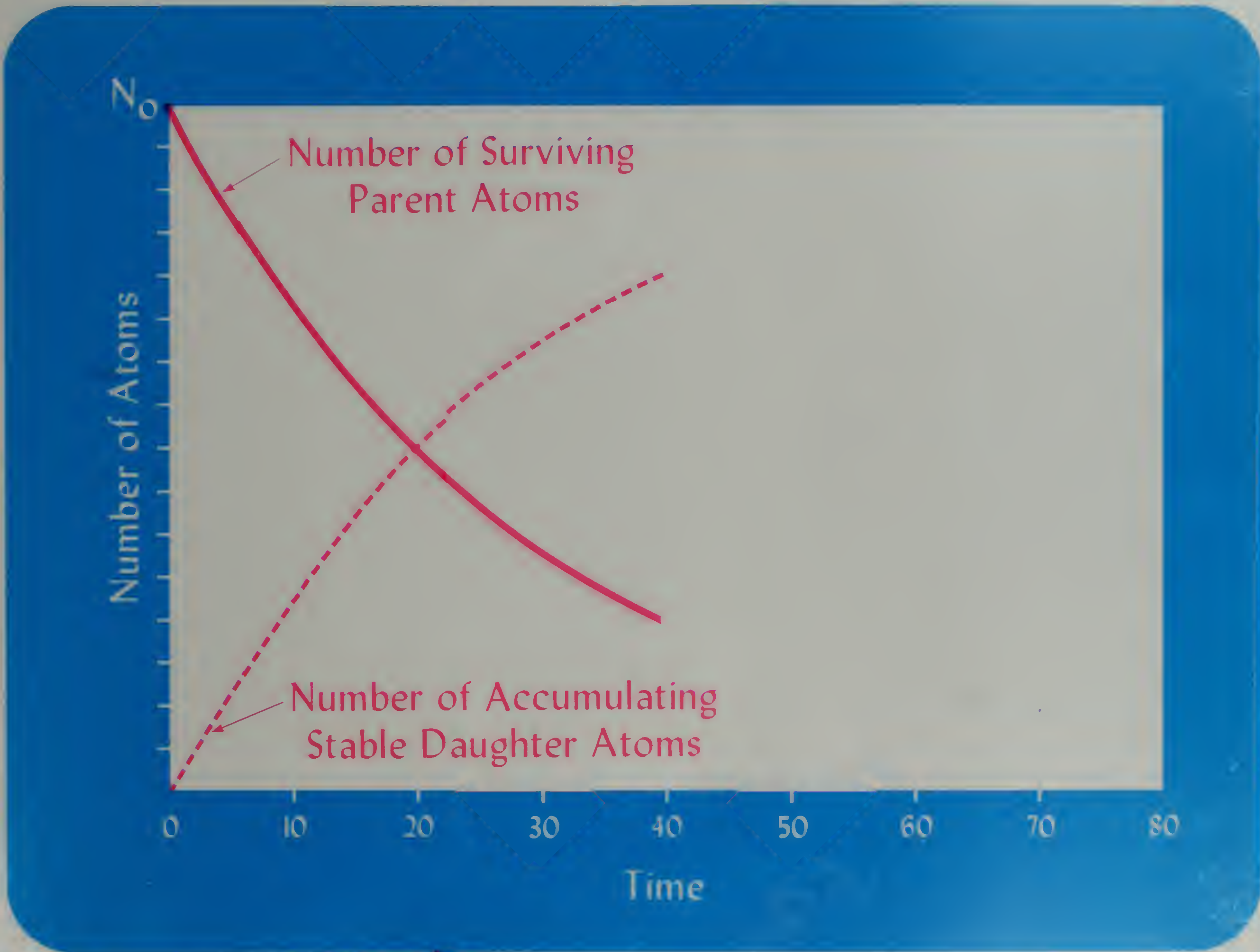
A
B


N_0
Number of Surviving Parent Atoms
Number of Accumulating Stable Daughter Atoms
Number of Atoms
0
10
20
30
40
50
60
70
80
Time

A
B
C

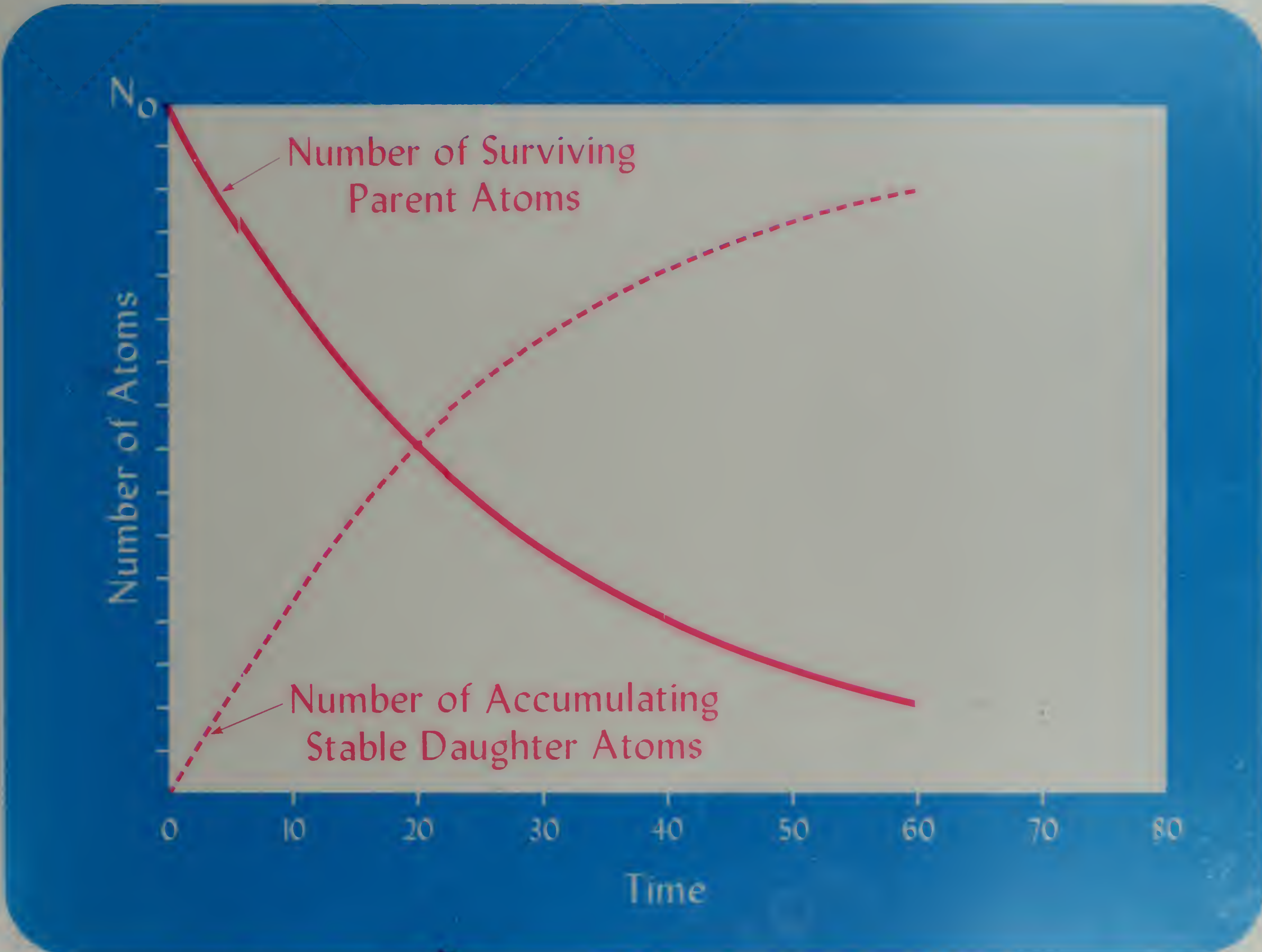


N_o
Number of Surviving Parent Atoms
Number of Accumulating Stable Daughter Atoms
Number of Atoms
0
10
20
30
40
50
60
70
80
Time

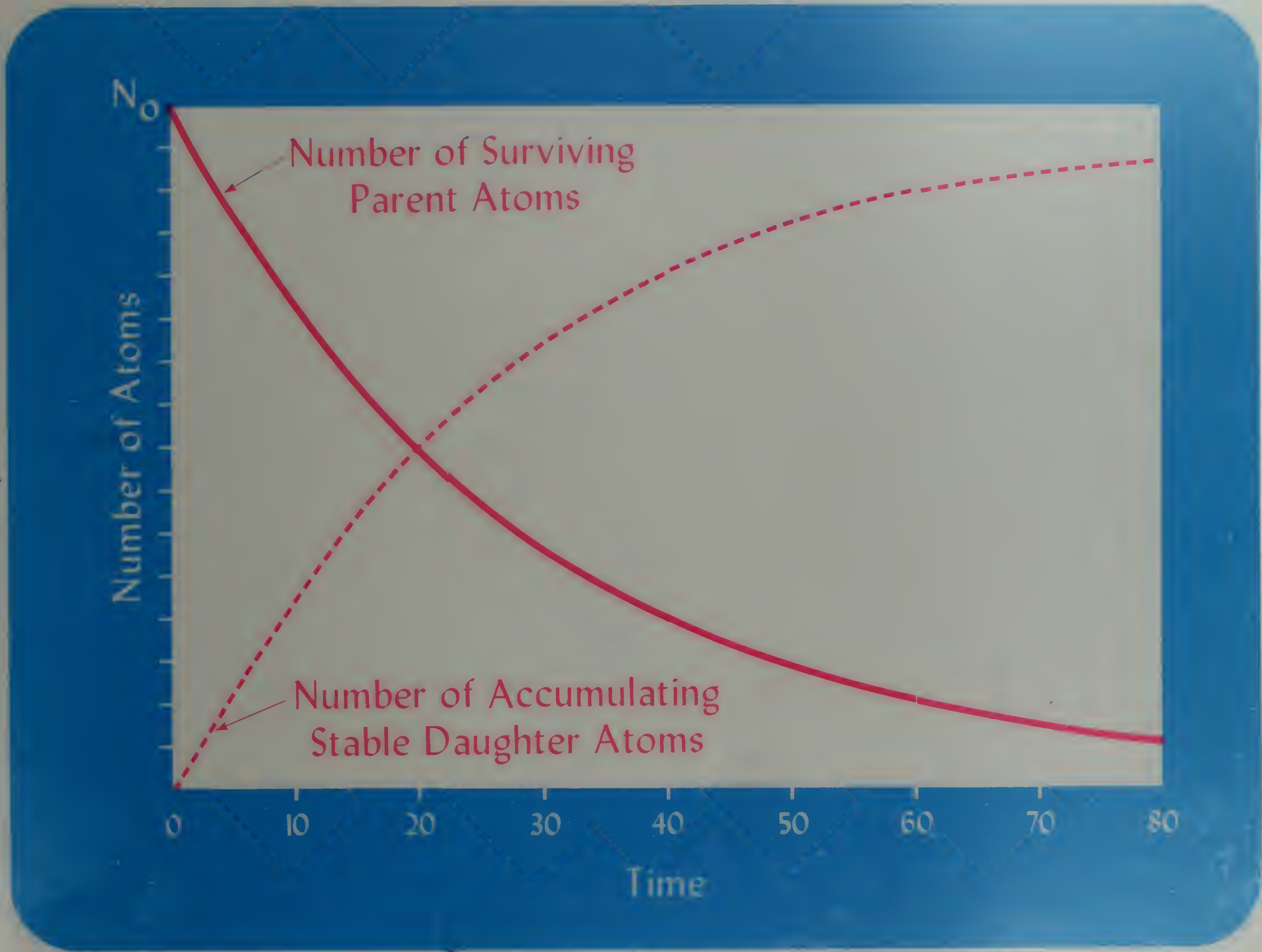


N_0
Number of Surviving Parent Atoms
Number of Accumulating Stable Daughter Atoms
Number of Atoms
0
10
20
30
40
50
60
70
80
Time

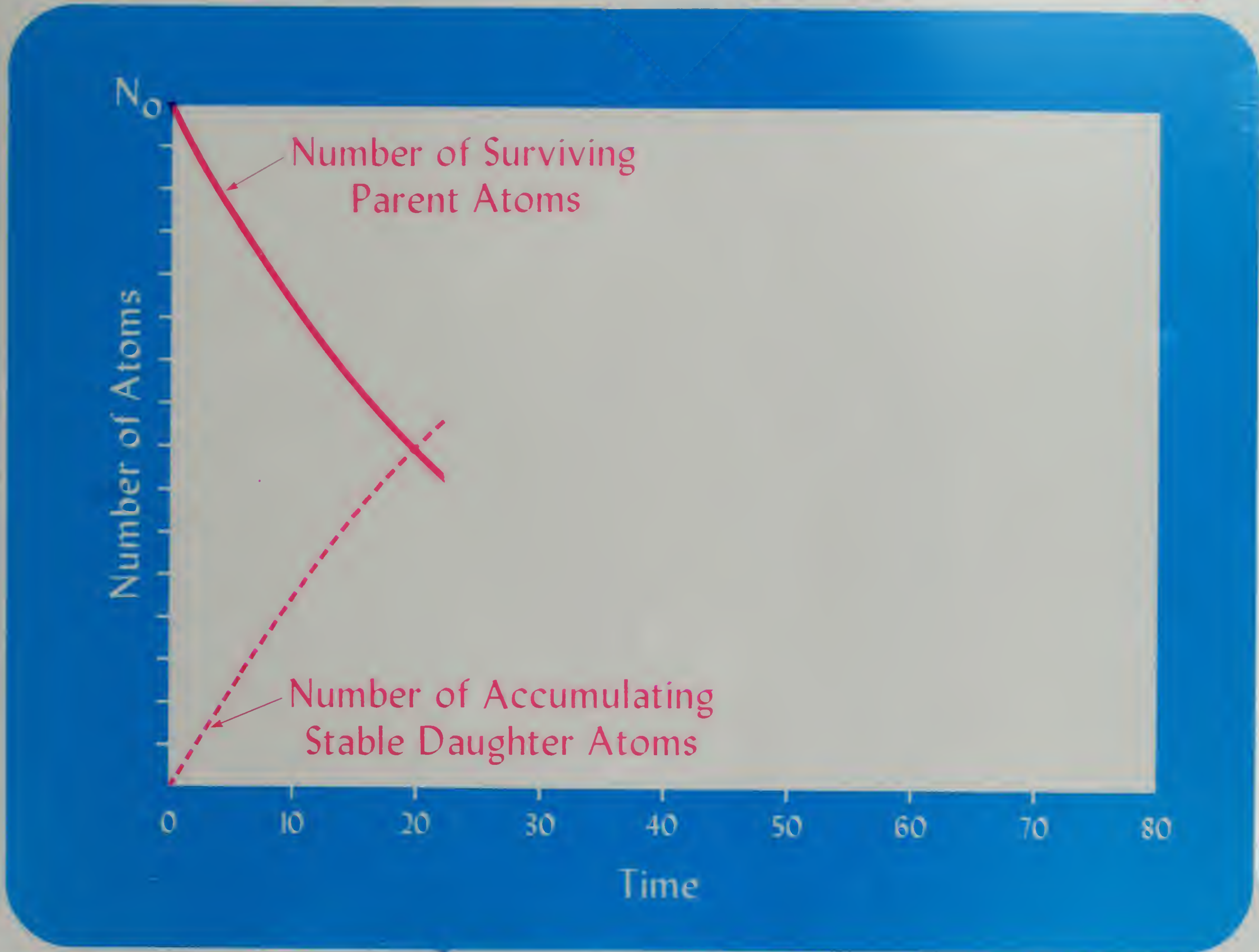
A
B
C
D

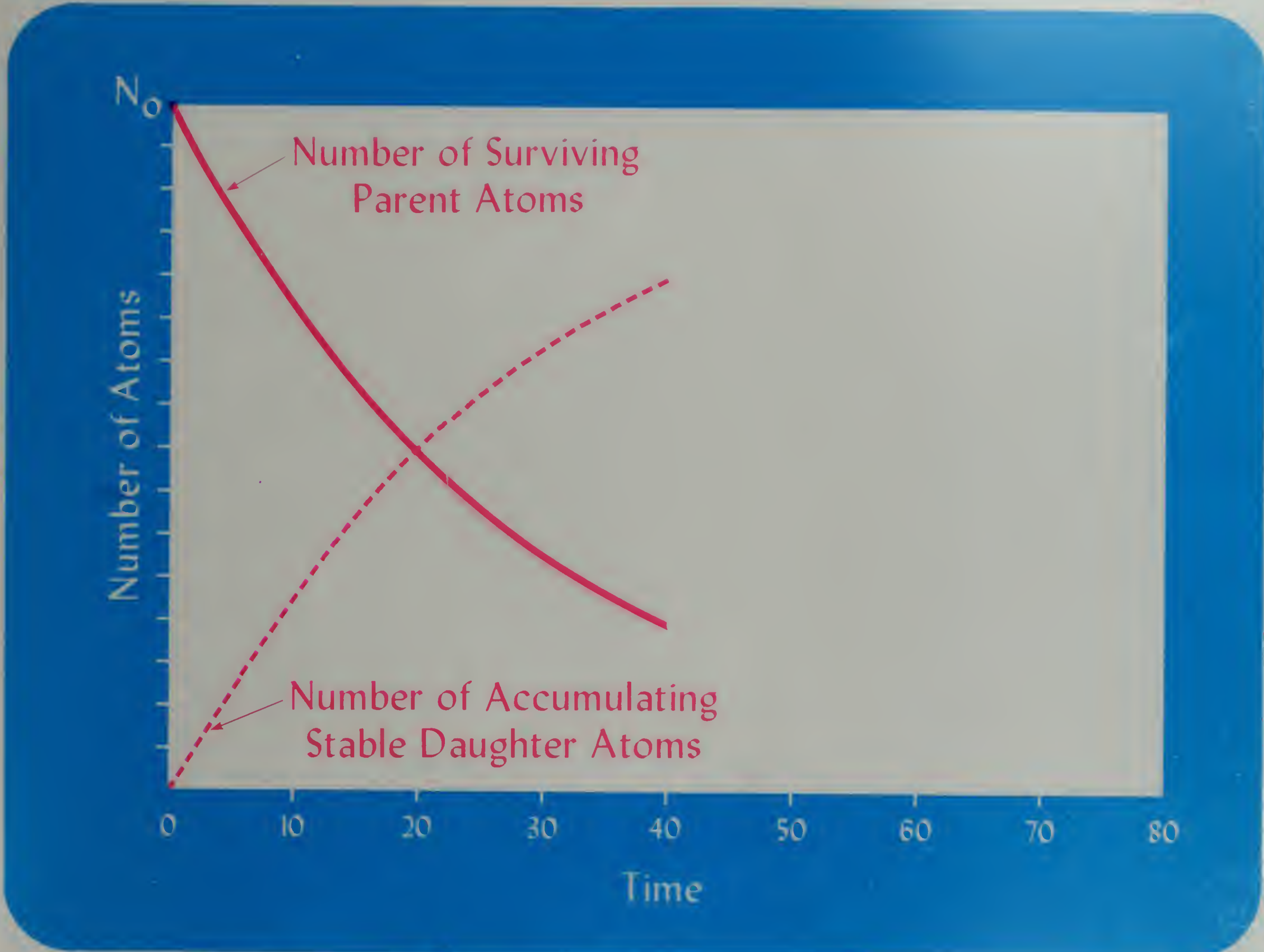


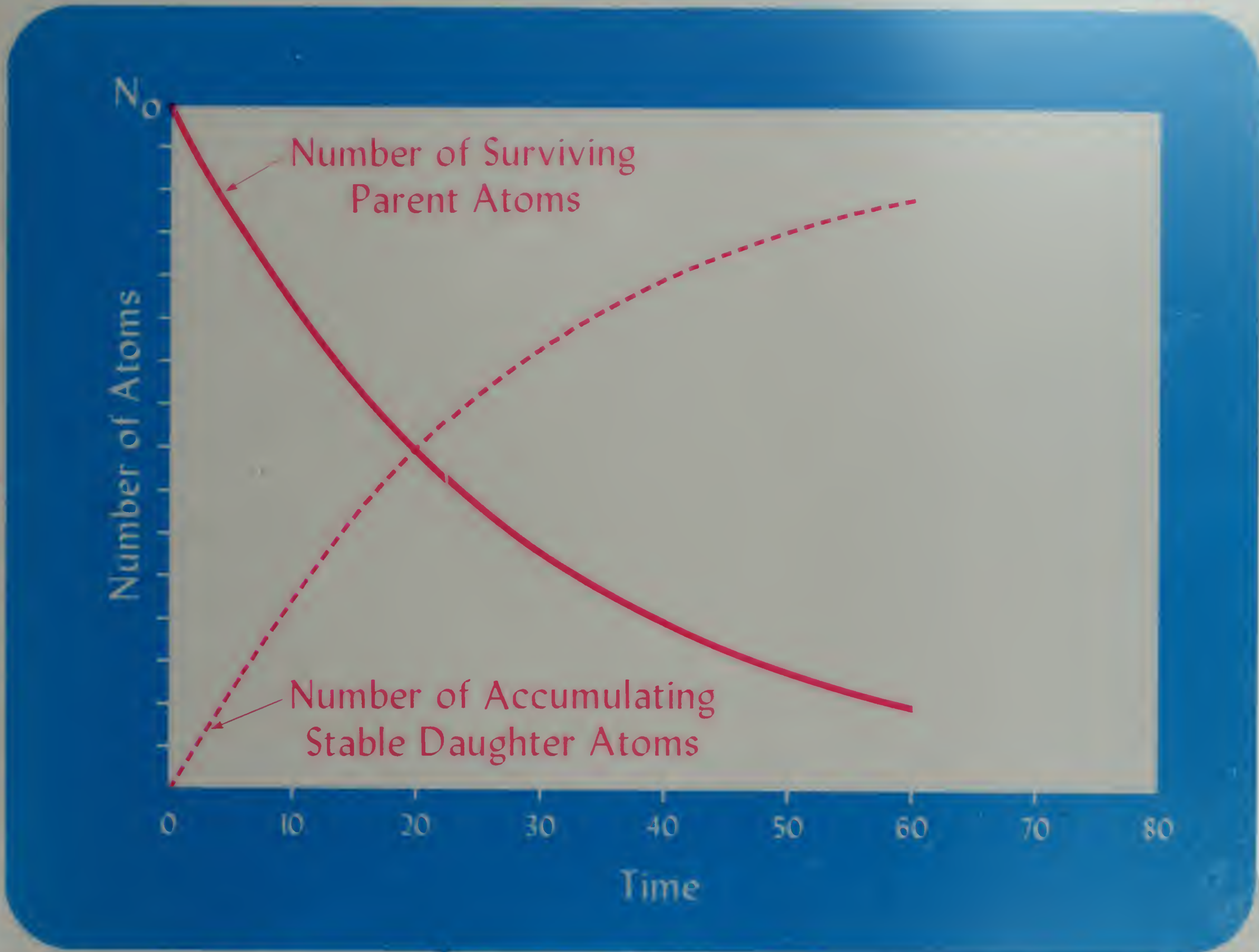
N_0
Number of Surviving Parent Atoms
Number of Accumulating Stable Daughter Atoms
Number of Atoms
0
10
20
30
40
50
60
70
80
Time



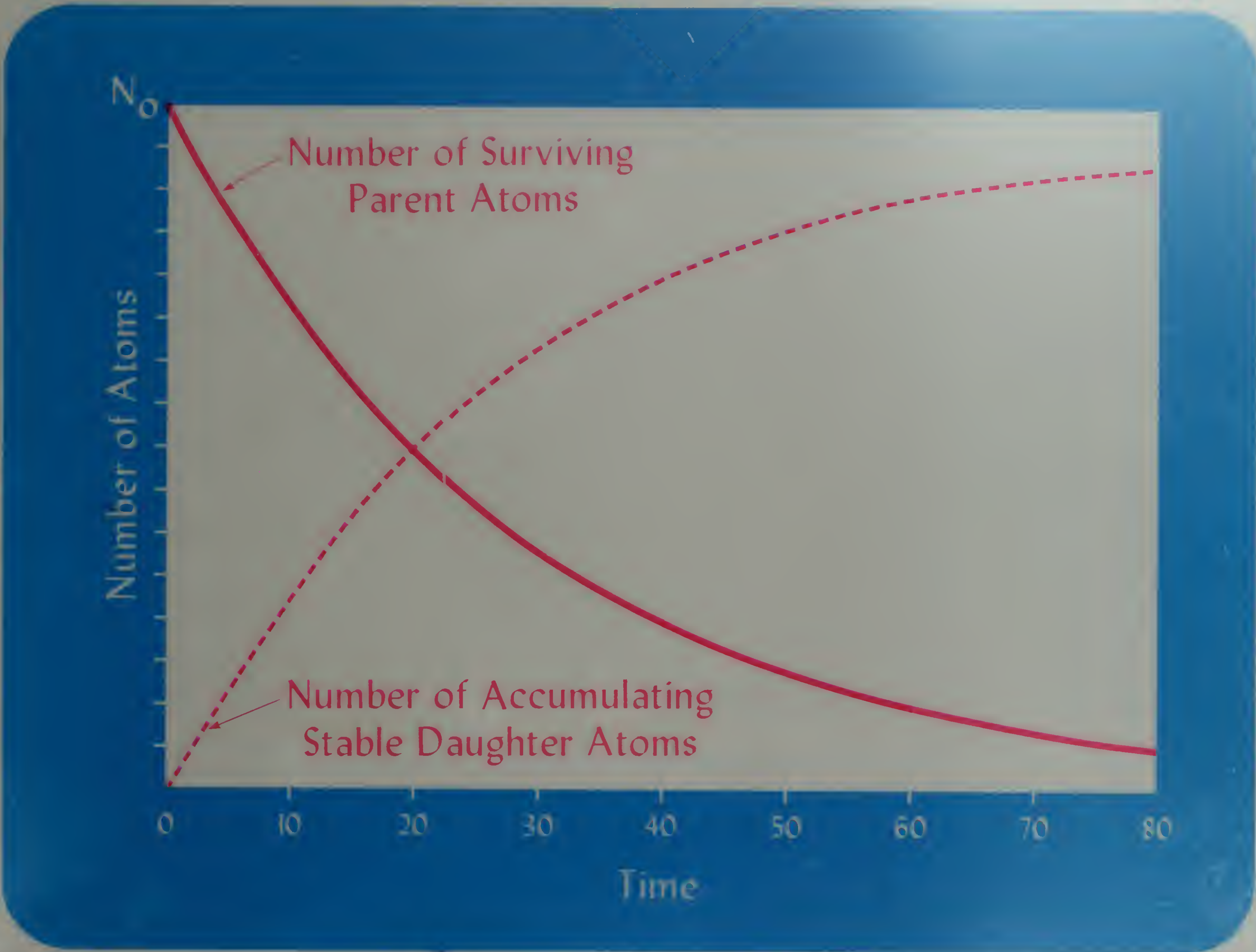
N0
Number of Surviving Parent Atoms
Number of Accumulating Stable Daughter Atoms
Number of Atoms
0
10
20
30
40
50
60
70
80
Time


N_o
Number of Surviving Parent Atoms
Number of Accumulating Stable Daughter Atoms
Number of Atoms
0
10
20
30
40
50
60
70
80
Time


N0
Number of Atoms
Number of Surviving
Parent Atoms
Number of Accumulating
Stable Daughter Atoms
0
10
20
30
40
50
60
70
80
Time


N_o
Number of Surviving Parent Atoms
Number of Accumulating Stable Daughter Atoms
Number of Atoms
0
10
20
30
40
50
60
70
80
Time

A
B
C
D
E


N_0
Number of Surviving
Parent Atoms
Number of Accumulating
Stable Daughter Atoms
Number of Atoms
0
10
20
30
40
50
60
70
80
Time

T44 Radioactive Displacement Rules

T44

Radioactive Displacement Rules

This transparency will be useful in leading a teacher-directed discussion of the Displacement Rules of Radioactivity. Space is provided to write in more examples of each type of decay: alpha decay, beta— decay, and beta+ decay.

Overlay T44-A — Shows the first rule in a visualized "before-after" diagram. Before the α particle is ejected, the radioactive nucleus contains A nucleons, Z of which are protons. After the α is emitted, the nucleus possesses 4 less nucleons, 2 of which are protons. The nucleus is now a new element of atomic number Z-2. Introduce T44-B with a mask.

Overlay T44-B — Shows the α decay displacement rule in the form of a general equation. Below is a specific example. Mask the Th-234 and ask students to present the result. Space is provided for writing-in further examples:

$${}_{88}Ra^{224} \longrightarrow {}_{86}Rn^{220} + {}_{2}He^{4}$$

$${}_{83}Bi^{212} \longrightarrow {}_{81}Tl^{208} + {}_{2}He^{4}$$

Remove overlays T44-A and B. Introduce overlay T44-C.

Overlay T44-C — Shows the second rule in a visualized "before-after"diagram. Before the β^- particle is ejected, the radioactive nucleus contains A nucleons, Z of which are protons. After the β^- is emitted, the nucleus retains its original mass number but increases its atomic number by one unit. An antineutrino $\bar{\nu}$ is also given off but it does not affect A to Z. Introduce T44-D with a mask.

Overlay T44-D — Shows the β^- decay displacement rule in the form of a general equation. Below is a specific example. Mask the Pa-234 and ask students to present the result. Space is provided for writing in further examples:

$${}_{83}Bi^{213} \longrightarrow {}_{84}Po^{213} + {}_{-1}e^{0} + \bar{\nu}$$

$${}_{94}Pu^{241} \longrightarrow {}_{95}Am^{241} + {}_{-1}e^{0} + \bar{\nu}$$

Remove overlays T44-C and D. Introduce overlay T44-E.

Overlay T44-E — Shows the third rule in a visualized "before-after" diagram. Before the positron is ejected, the radioactive nucleus contains A nucleons, Z of which are protons. After the β^+ is emitted, the nucleus retains its original mass number but decreases its atomic number by one unit. A neutrino ν is also given off but it does not affect A or Z. Introduce T44-F with a mask.

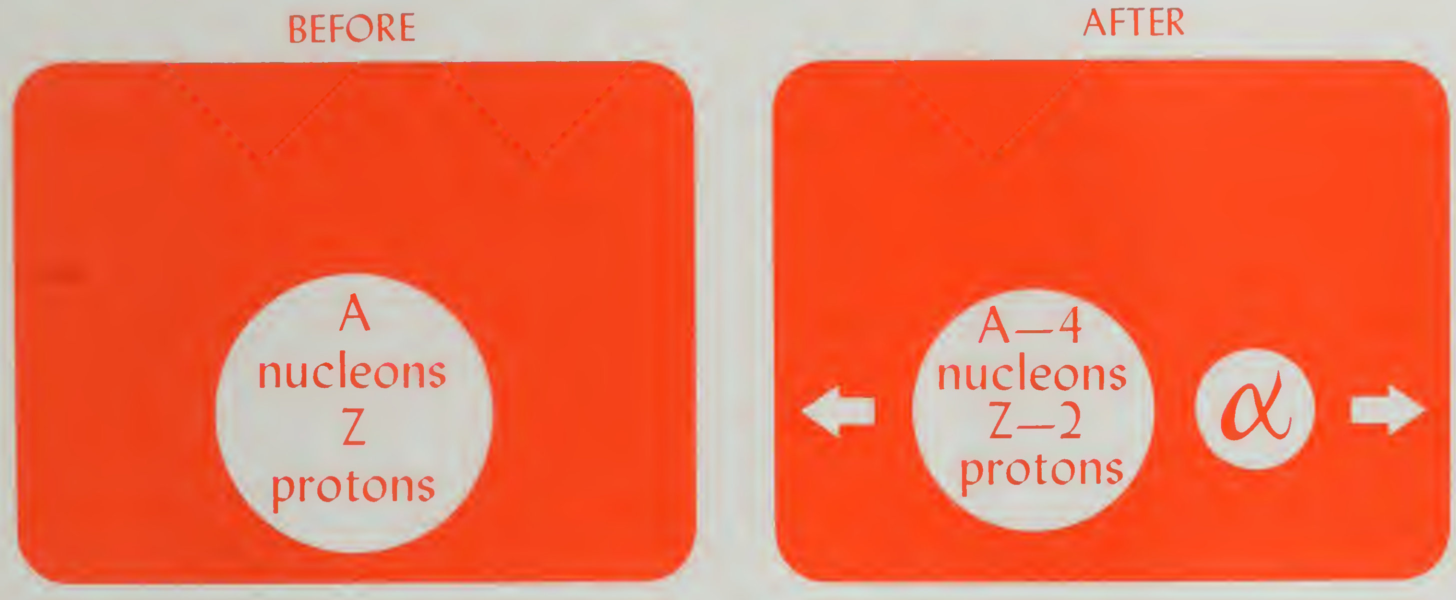
Overlay T44-F — Shows the β^+ decay displacement rule in the form of a general equation. Below is a specific example. Mask the Si-30 and ask students to present the result. Space is provided for writing-in further examples:

$${}_{7}N^{13} \longrightarrow {}_{6}C^{13} + {}_{1}e^{0} + \nu$$

$${}_{9}F^{18} \longrightarrow {}_{8}O^{18} + {}_{1}e^{0} + \nu$$

A

α DECAY



A
B

α DECAY

BEFORE

AFTER

$$ {}_{Z}X^{A} \longrightarrow {}_{Z-2}Y^{A-4} + {}_{2}He^{4} $$

A
nucleons
Z
protons

A—4
nucleons
Z—2
protons

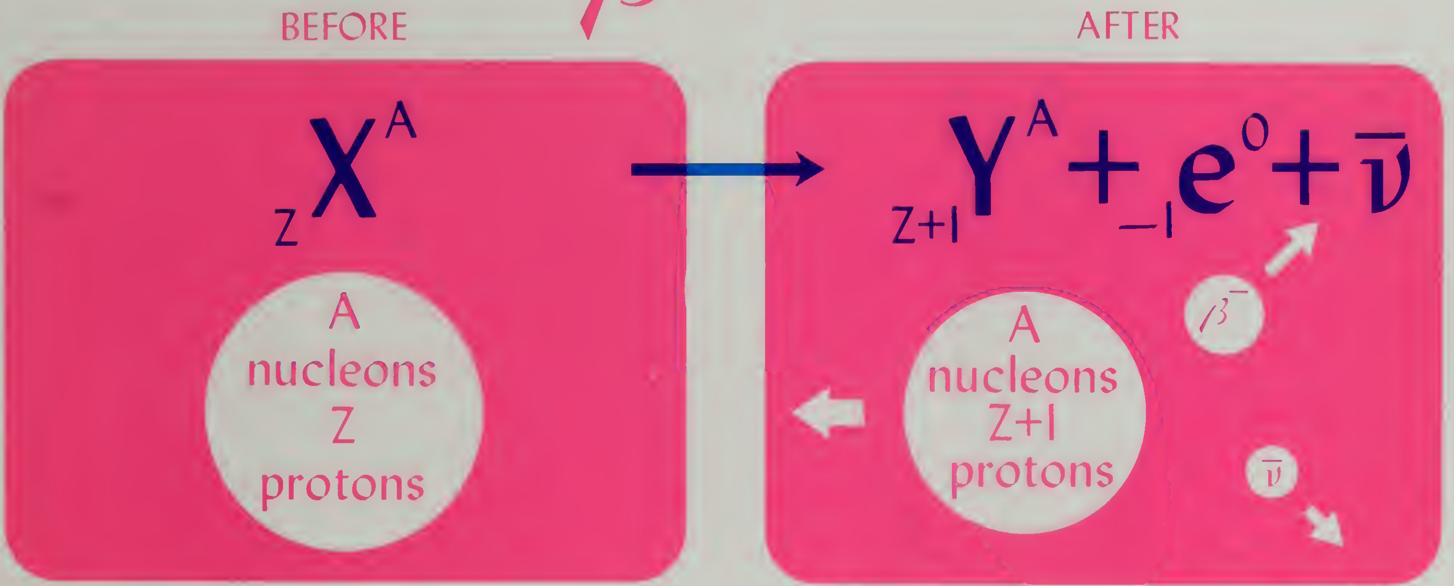
α

$$ {}_{92}U^{238} \longrightarrow {}_{90}Th^{234} + {}_{2}He^{4} $$

β^- DECAY


BEFORE
A
nucleons
Z
protons
AFTER
A
nucleons
Z+1
protons
β^-
$\bar{\nu}$

β^- DECAY

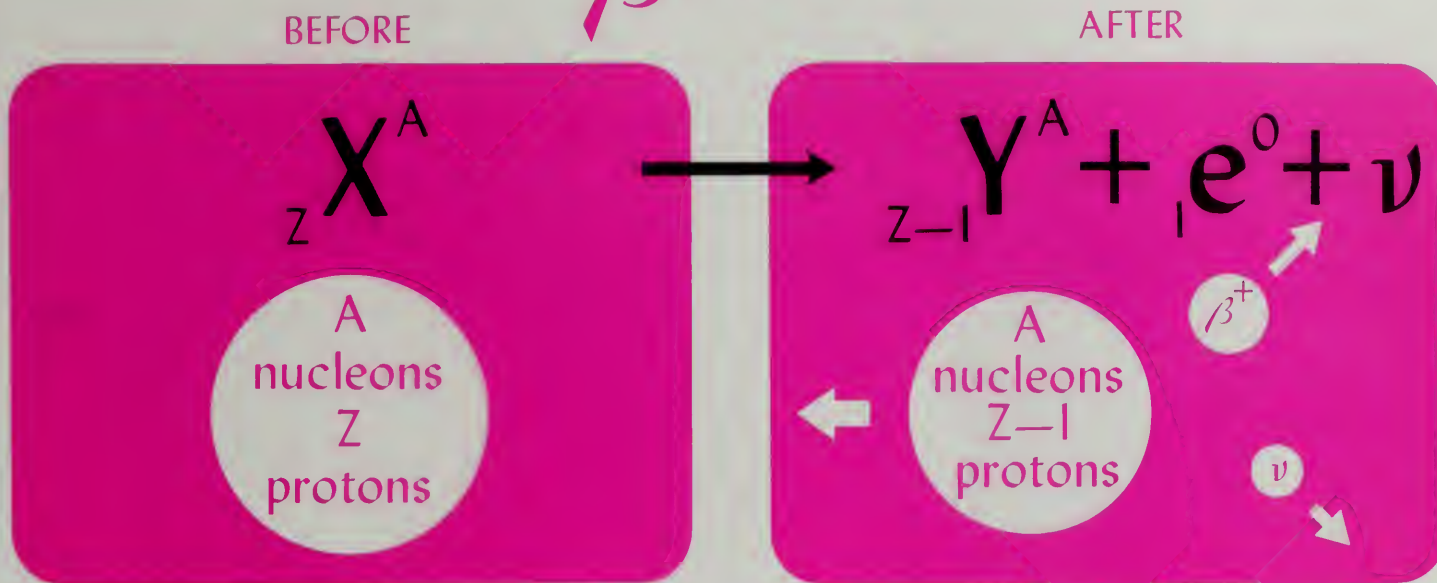


$$_{90}Th^{234} \longrightarrow {}_{91}Pa^{234} + {}_{-1}e^{0} + \bar{\nu}$$

β^+ DECAY


BEFORE
AFTER
A
nucleons
Z
protons
A
nucleons
Z—1
protons
β^+
ν

β^{+} DECAY



$$ {}_{15}P^{30} \longrightarrow {}_{14}Si^{30} + {}_{1}e^{0} + \nu $$

T45 Mass Spectrograph

Mass Spectrograph

A schematic diagram of the apparatus known as the mass spectrograph is presented in this transparency. Overlays illustrate the operation of the velocity selector and the mass-determining section of the spectrograph.

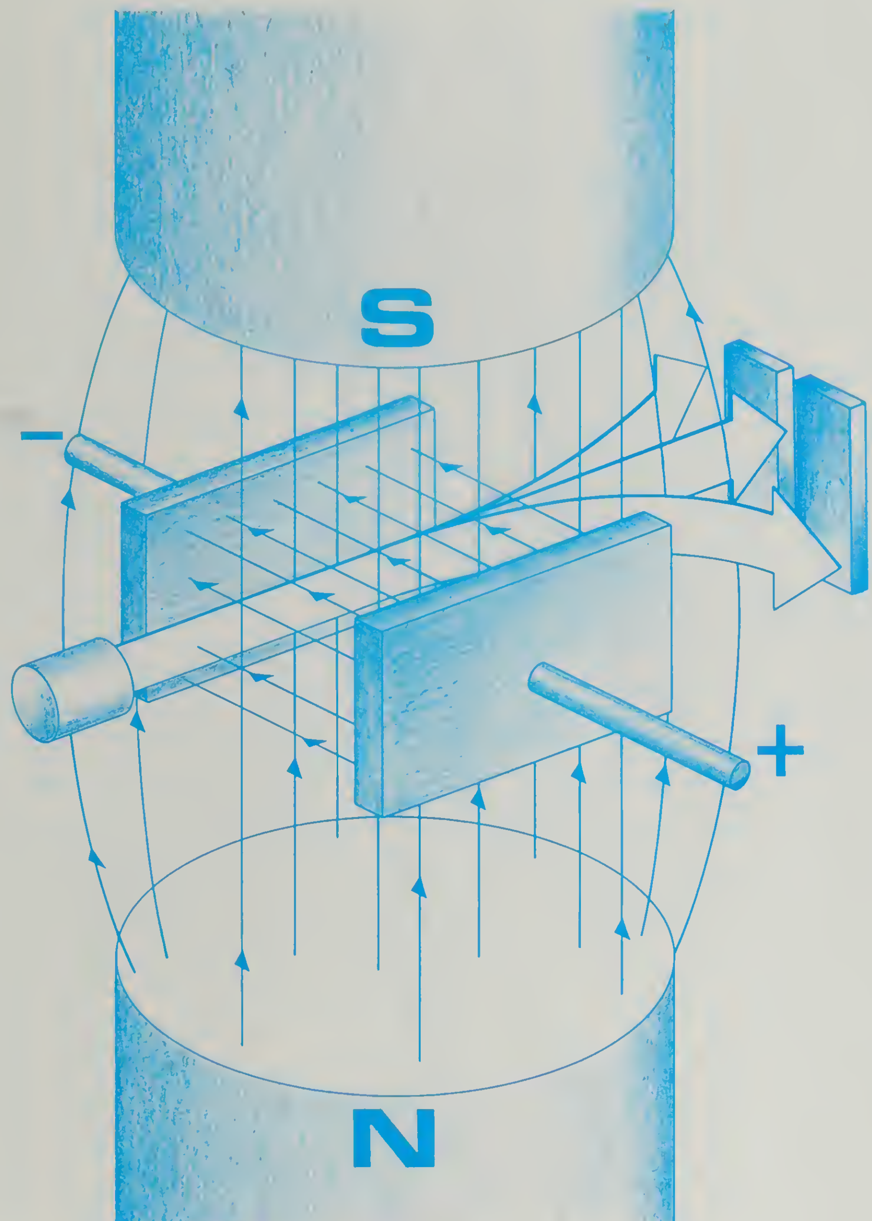
Overlay T45-A Shows the arrangement of magnetic and electric fields used to select ions of a certain speed. The electric and magnetic forces on ions in the beam are in opposite directions. The magnitude of the magnetic force increases with the speed of the ions. Only those ions on which the magnitude of the magnetic force equals the magnitude of the electric force will be undeflected and pass through the slit. Three beams are shown, one of ions moving too slowly, one of ions moving too rapidly, and one of ions moving at just the right speed to pass through the slit. For these ions F mag = F elect, that is, $qvB = qE$. So the speed of ions going through the slit is $v = E/B$. Introduce overlay T45-B.

Overlay T45-B Shows an undeflected beam passing through the slits and entering a second magnetic field B' produced by a separate magnet. The beam is now acted on only by this magnetic field which will cause it to follow a circular path. The centripetal force is supplied by the magnetic force $qvB' = mv^2/R$. The mass can now be determined by solving for m and substituting $v = E/B$ into the equation. Thus

$$m = \frac{qBB'R}{E}$$

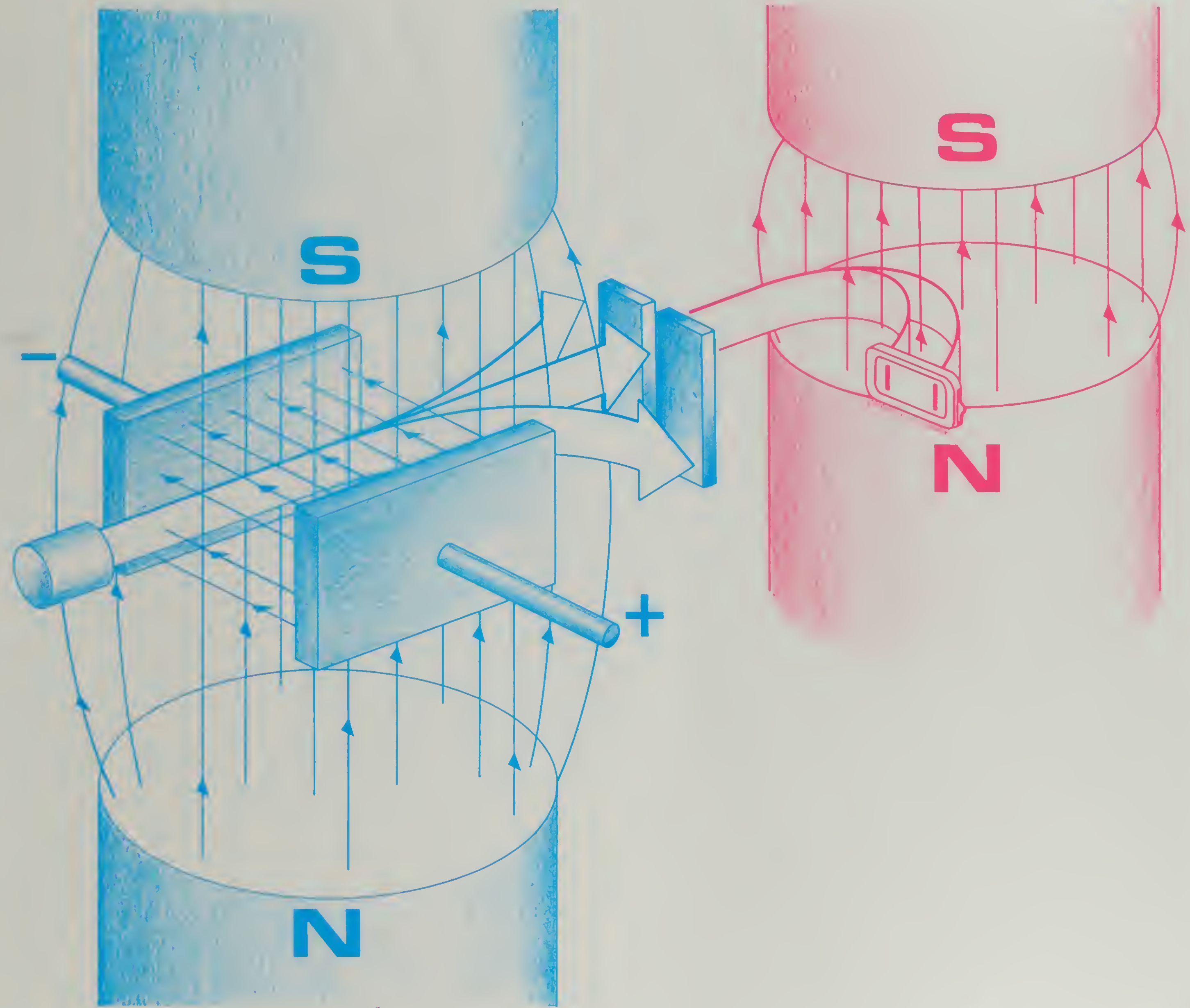
The radius of curvature R can be measured with the aid of the film pack. The values B, B′ and E are determined from the design of the apparatus, and measurements of magnet current and plate voltage.

A



T

A
B



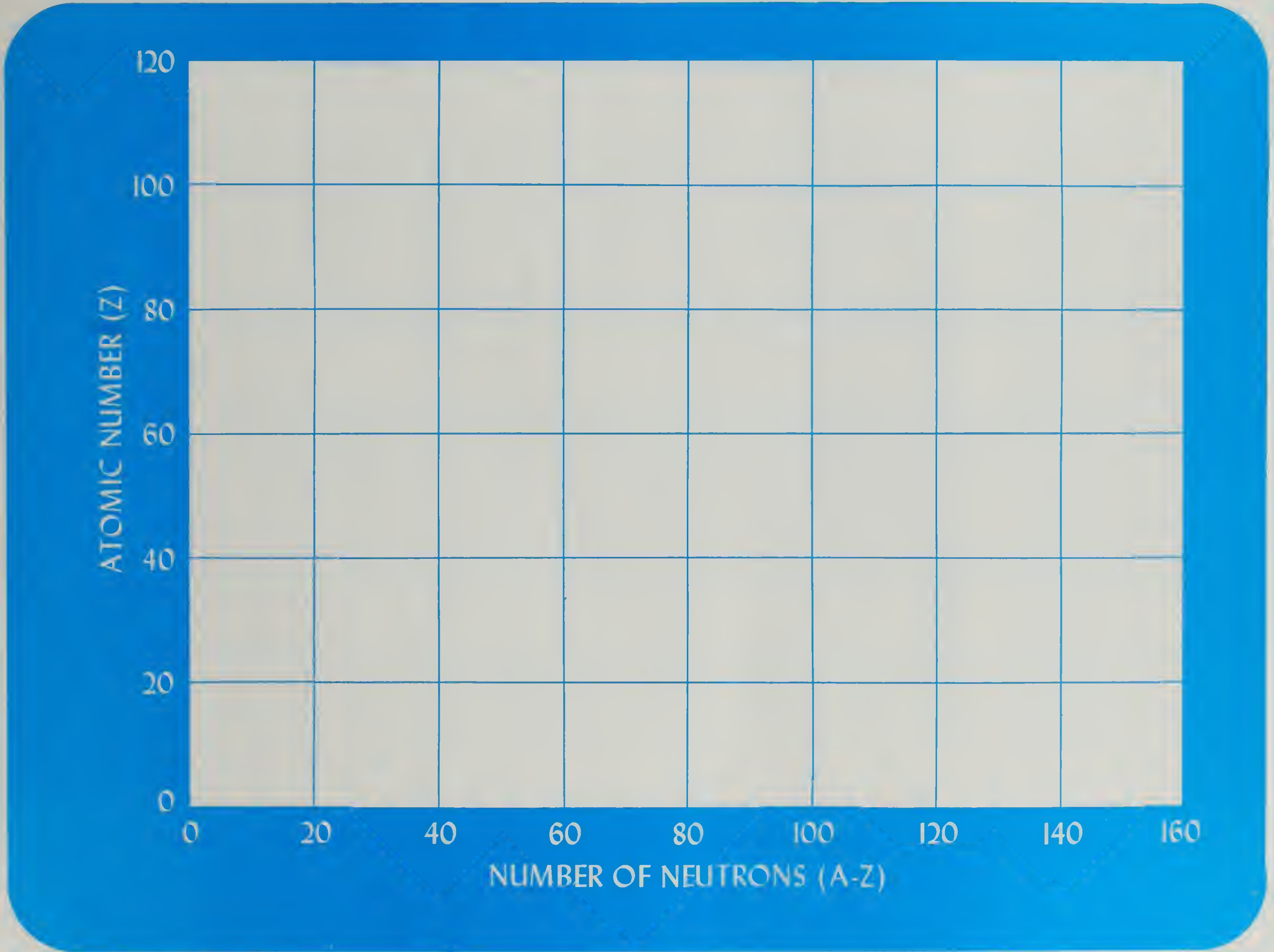
T46 Chart of the Nuclides

Chart of the Nuclides

This transparency is based upon the "Chart of the Nuclides" published by the Knolls Atomic Power Laboratory, Schenectady, New York. It represents a plot of stable and unstable radioisotopes with other pertinent nuclear information.

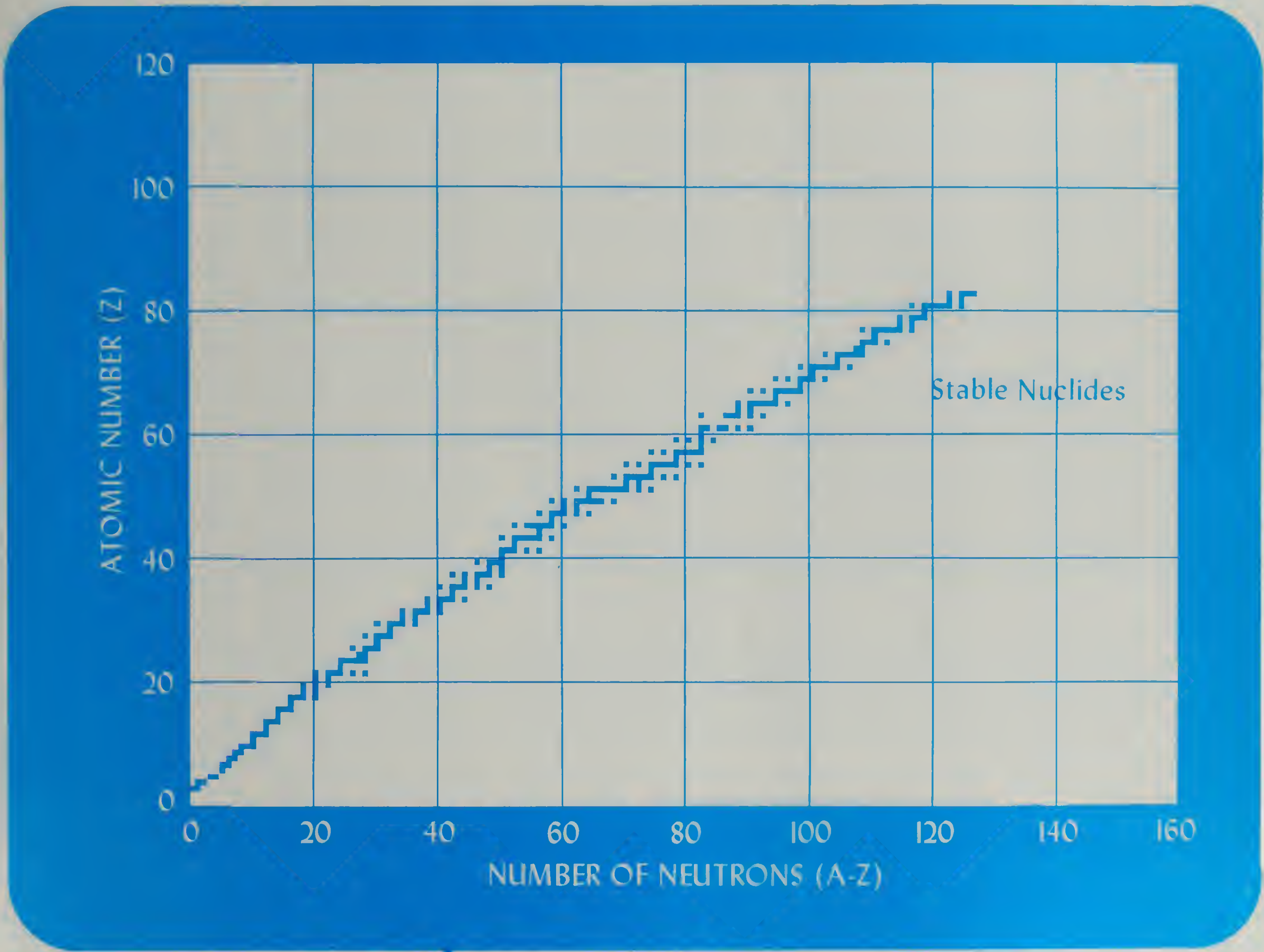
Overlay T46-A	Shows a grid with a vertical axis indicating the number of protons or the atomic number and the horizontal axis giving the number of neutrons or A-Z. Add overlay T46-B.
Overlay T46-B	Shows the positions of the 265 stable nuclides. Add overlay T46-C.
Overlay T46-C	Shows the positions of those radioactive nuclides which occur naturally. Add overlay T46-D.
Overlay T46-D	Shows the positions of the 265 stable and approximately 1130 radioactive isotopes. Add overlay T46-E.
Overlay T46-E	Shows a line plotting nuclides which contain equal numbers of protons and neutrons. Those nuclides with small atomic numbers lie on this line while those of higher atomic number possess more neutrons than protons. Add overlay T46-F.
Overlay T46-F	Shows those nuclides with nuclei possessing 2, 8, 20, 50, or 82 protons, or 2, 8, 20, 50, 82 or 126 neutrons. These nuclides are unusually stable. The numbers are referred to as "magic numbers". Remove overlays T46-F-E-D-C and introduce overlay T46-G.
Overlay T46-G	Shows a simplified detail of the chart indicating stable nuclides (large numbers) and those radioactive nuclides which experience positron decay and k-capture.

A

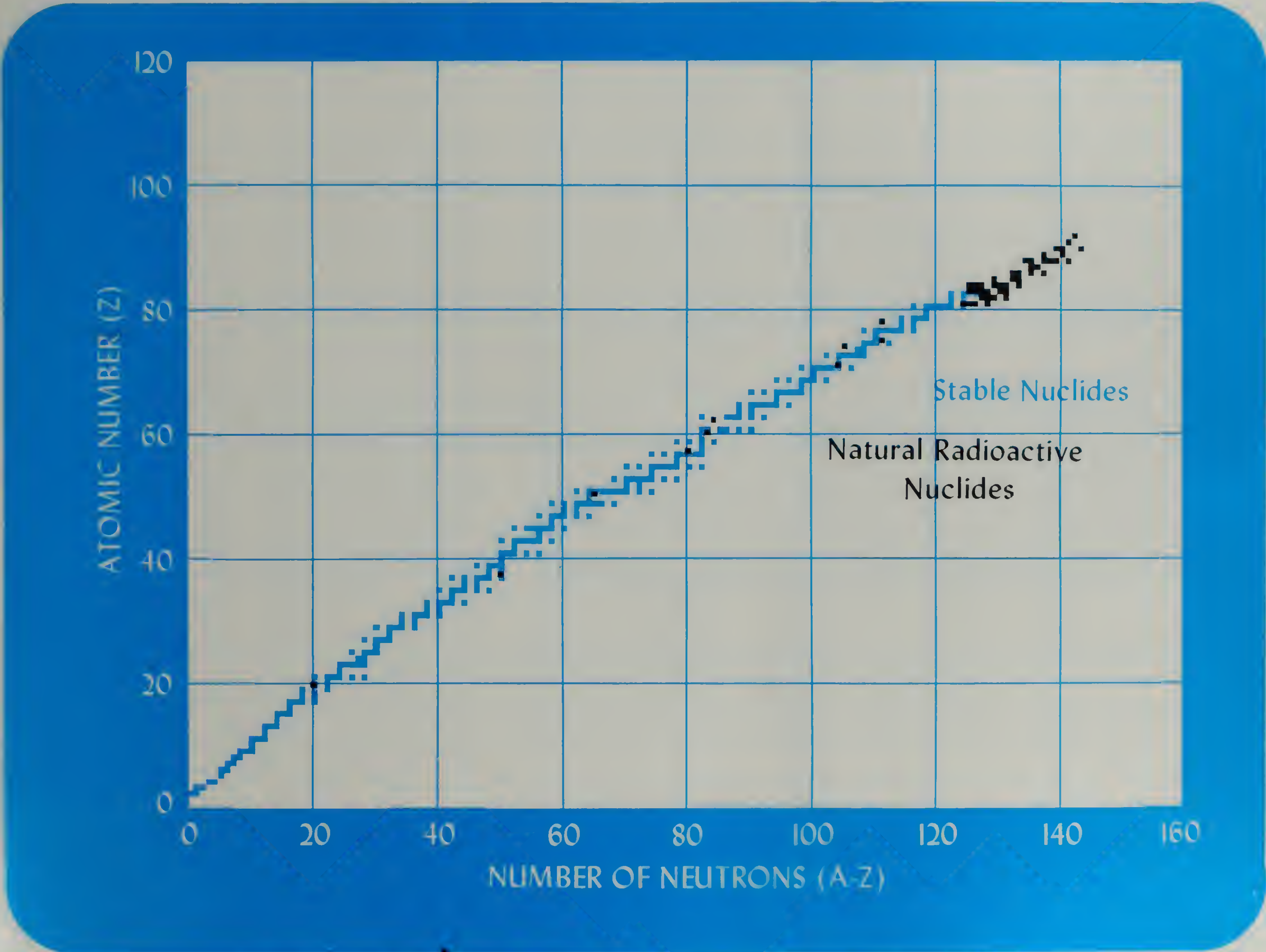


120
100
80
60
40
20
0
ATOMIC NUMBER (Z)
0
20
40
60
80
100
120
140
160
NUMBER OF NEUTRONS (A-Z)

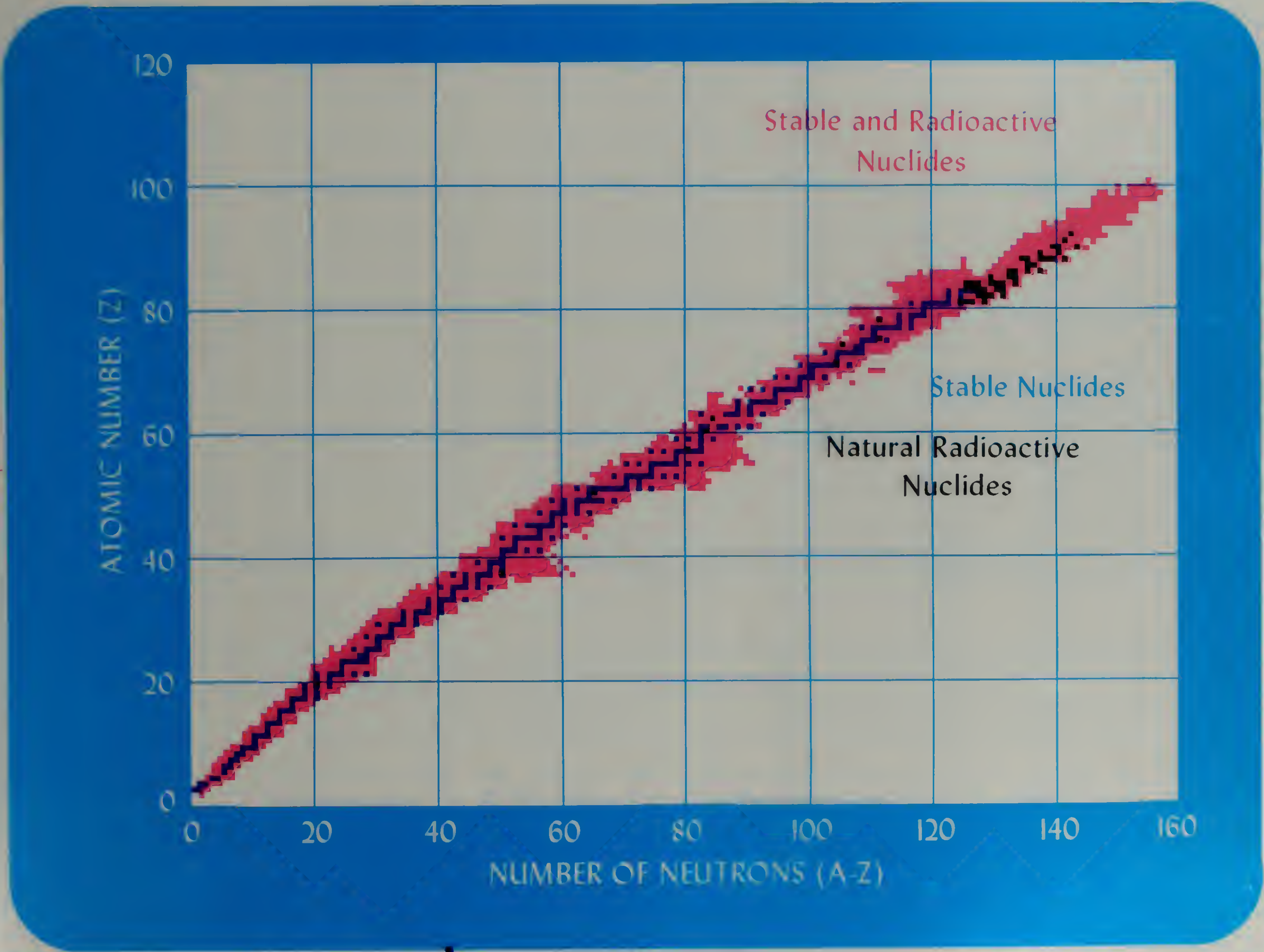
T

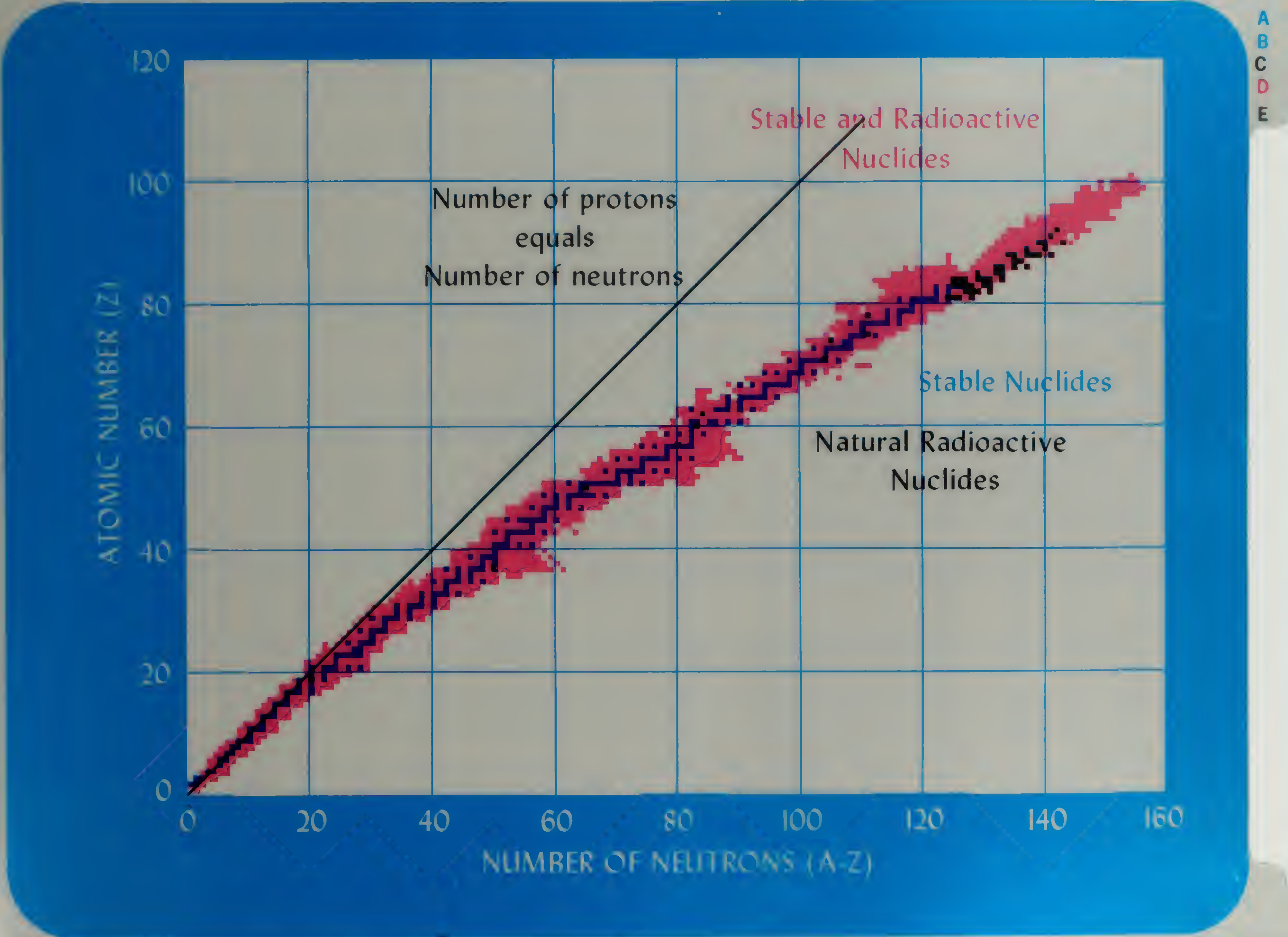

Stable Nuclides
ATOMIC NUMBER (Z)
NUMBER OF NEUTRONS (A-Z)
0
20
40
60
80
100
120
140
160

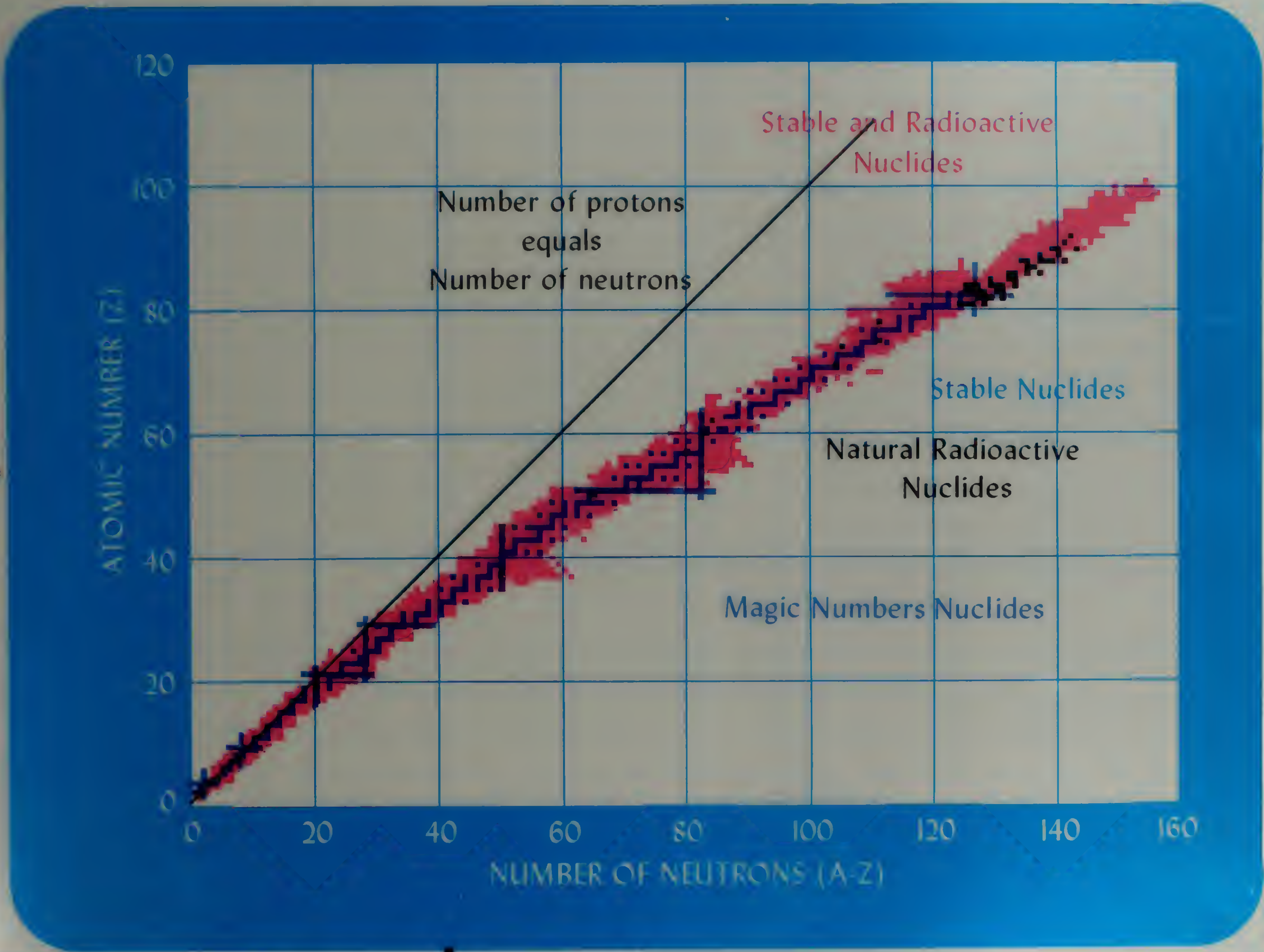
A
B
C


120
100
80
60
40
20
0
ATOMIC NUMBER (Z)
0
20
40
60
80
100
120
140
160
NUMBER OF NEUTRONS (A-Z)
Stable Nuclides
Natural Radioactive Nuclides

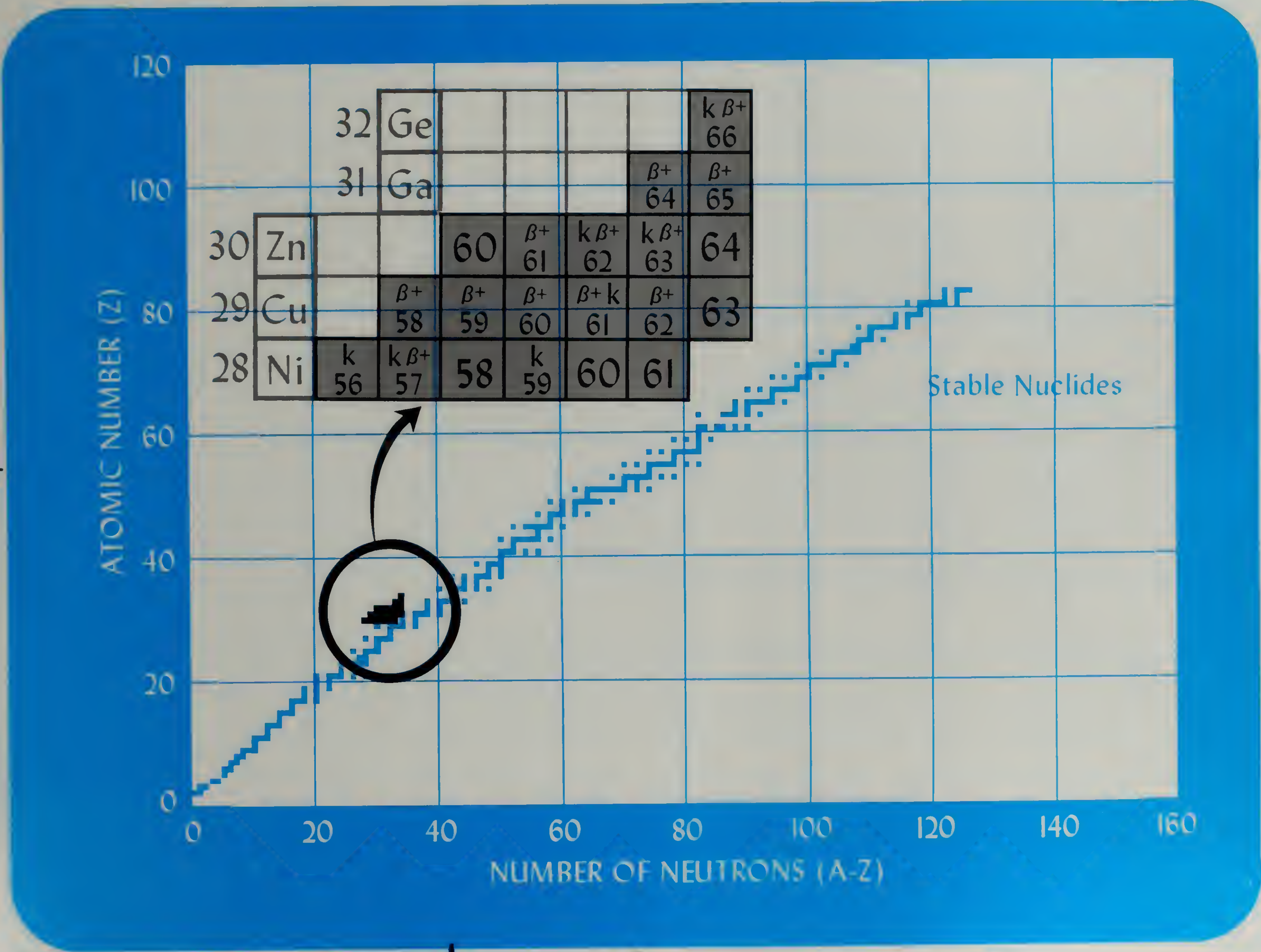
A
B
C
D


Stable and Radioactive Nuclides
Stable Nuclides
Natural Radioactive Nuclides
ATOMIC NUMBER (Z)
120
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
NUMBER OF NEUTRONS (A-Z)


Stable and Radioactive Nuclides
Number of protons equals Number of neutrons
Stable Nuclides
Natural Radioactive Nuclides
ATOMIC NUMBER (Z)
NUMBER OF NEUTRONS (A-Z)
0
20
40
60
80
100
120
140
160
A
B
C
D
E


Stable and Radioactive Nuclides
Number of protons equals Number of neutrons
Stable Nuclides
Natural Radioactive Nuclides
Magic Numbers Nuclides
ATOMIC NUMBER (Z)
NUMBER OF NEUTRONS (A-Z)
0
20
40
60
80
100
120
140
160

A
B
C
D
E



32 Ge
31 Ga
30 Zn
29 Cu
28 Ni
k β+ 66
β+ 64
β+ 65
60
β+ 61
k β+ 62
k β+ 63
64
β+ 58
β+ 59
β+ 60
β+ k 61
β+ 62
63
k 56
k β+ 57
58
k 59
60
61
Stable Nuclides
ATOMIC NUMBER (Z)
NUMBER OF NEUTRONS (A-Z)
0
20
40
60
80
100
120
140
160

T47 Nuclear Equations

Nuclear Equations

This transparency will be useful in presenting the nuclear equations associated with certain major events in the history of nuclear physics: the first artificial transmutation; the discovery of the neutron; and the mass-energy relation.

Overlay T47-A Shows visualizations for two nuclear reactions: the upper one represents the first artificial transmutation of an atom of one chemical element into an atom of another chemical element; the lower one represents the nuclear reaction for the discovery of the neutron. Mask that segment which is not being discussed at the moment. This overlay is essentially for visualizing the capture of the α particle by the target nucleus and its subsequent transmutation and release of one of its nucleons. It will also serve to emphasize the conservation of charge and mass number. Introduce overlay T47-B.

Overlay T47-B Shows the nuclear equations for these reactions along with black spheres to distinguish protons from neutrons in the nucleus. The "compound intermediate" ${}_9F^{18}$ is included to emphasize the capture of the α particle by the N-14 nucleus. Remove overlays T47-A and B. Introduce overlay T47-C.

Overlay T47-C Shows the nucleons involved in a nuclear reaction exhibiting a loss of rest mass. Add overlay T47-D.

Overlay T47-D Shows the nuclear equation for the reaction and indicates which nucleons are protons. In addition, the rest mass of each nucleus is presented in ATOMIC MASS UNITS. Space is provided to compute the mass defect from which the mass-energy relation may be discussed.

A

A
B

$$ {}_{2}He^{4} + {}_{7}N^{14} \rightarrow ({}_{9}F^{18}) \rightarrow {}_{8}O^{17} + {}_{1}H^{1} $$

$$ {}_{2}He^{4} + {}_{4}Be^{9} \longrightarrow {}_{6}C^{12} + {}_{0}n^{1} $$

C

T

 T-47

C
D

$$ {}_{1}H^{1} + {}_{3}Li^{7} \rightarrow ({}_{4}Be^{8}) \rightarrow {}_{2}He^{4} + {}_{2}He^{4} $$

1.007825 7.016005 4.002603 4.002603

T48

T48 Binding Energy Curves

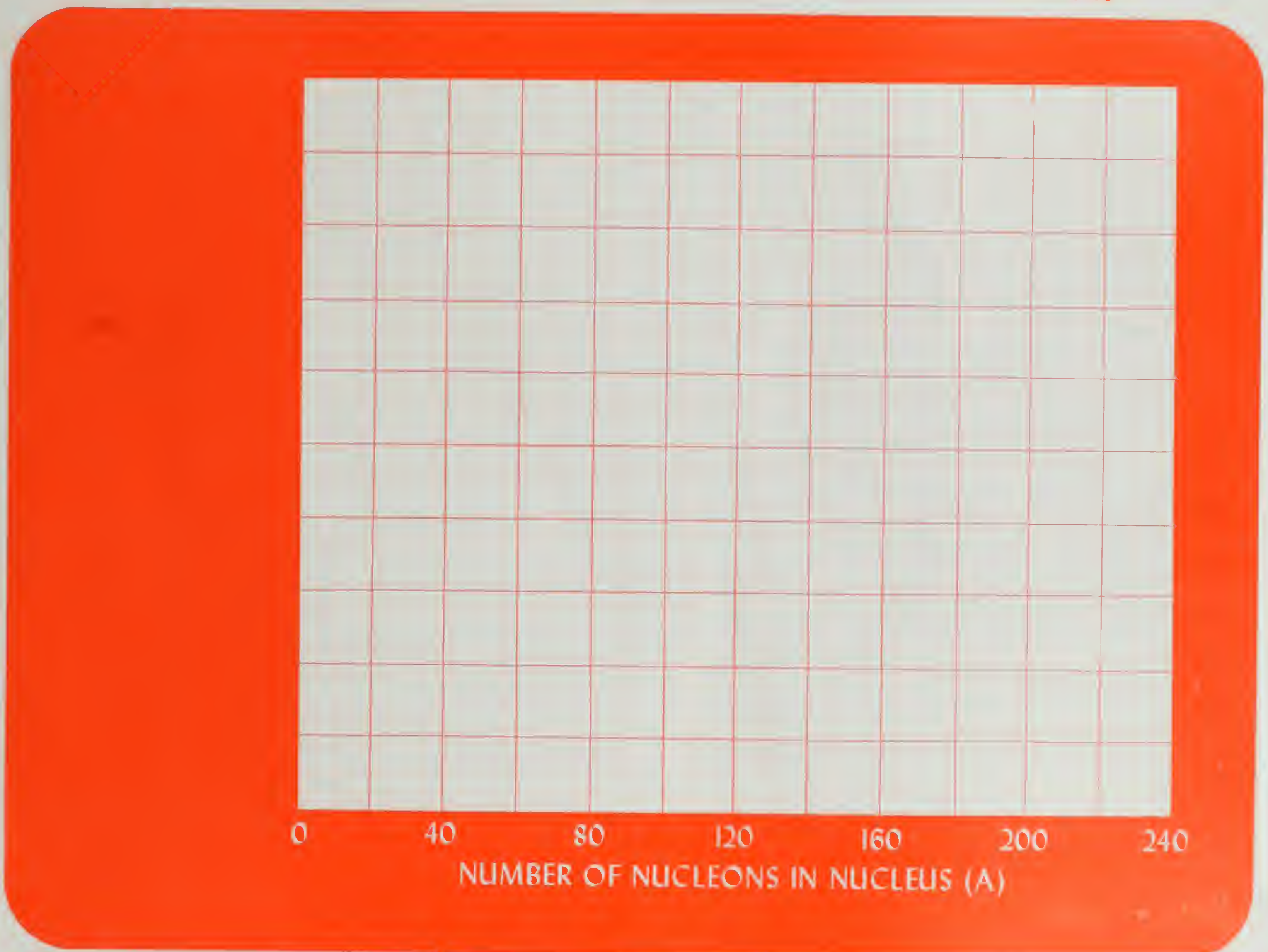
Binding Energy Curves

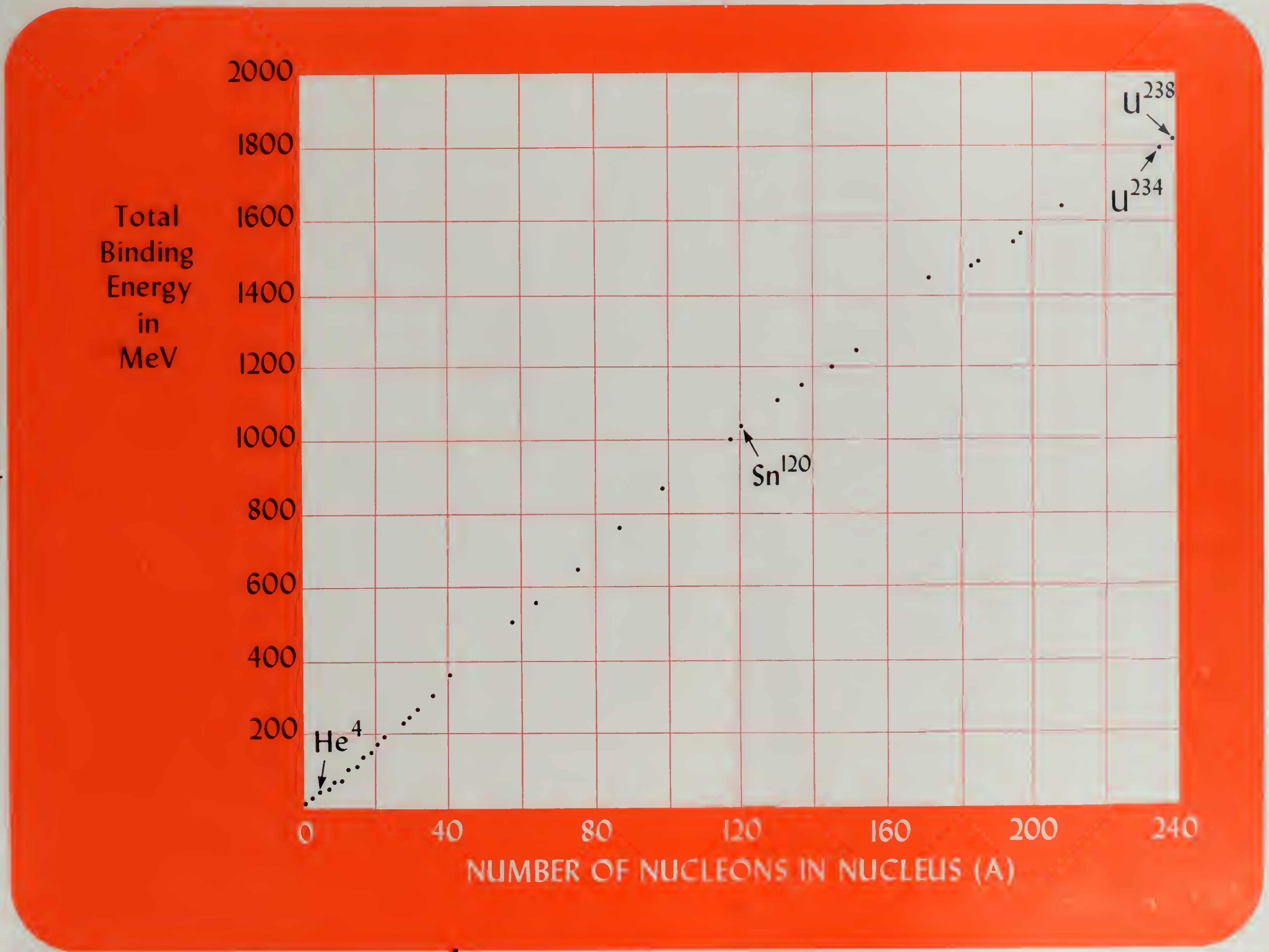
This transparency presents plots for the total binding energy of nuclei and the average binding energy per nucleon.

Overlay T48-A — Shows a grid with the number of nucleons in the nucleus plotted along the horizontal axis. The vertical axis will be determined by the subsequent overlays. Introduce overlay T48-B.

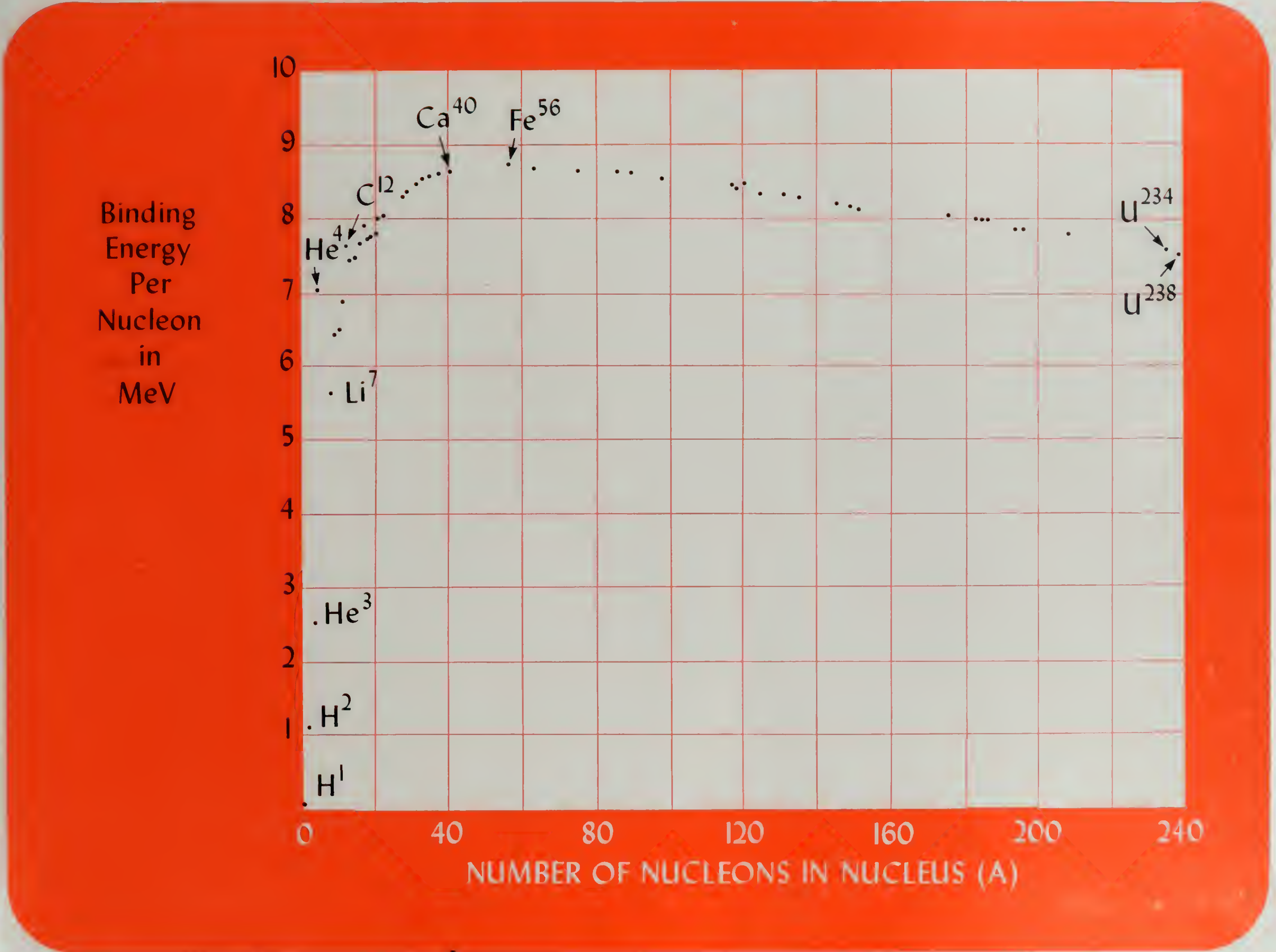
Overlay T48-B — Shows a plot of the total binding energy for 47 nuclides. The total binding energy is defined as the difference between the sum of the rest masses of the protons and neutrons in the free state and the rest mass of the nucleus containing the same number of nucleons. The values run from 2.2 MeV for H-2 to 1803 MeV for U-238. The value for Sn-120 is 1020 MeV; for He-4 it is 28.3 MeV. Remove this overlay and introduce T48-C.

Overlay T48-C — Shows a plot of the average binding energy per nucleon for the same 47 nuclides. To compute the binding energy per nucleon simply divide the previously determined total binding energy by the number of particles in the nucleus. The binding energy per nucleon is seen to be highest for the middle elements — the most stable nuclei. The average binding energy per nucleon curve is useful in predicting energy releases in nuclear reactions. When the products of a nuclear reaction lie higher on the binding energy curve than do the reactants, they have more binding energy per particle and release energy equal to the increase in the total binding energy.


0
40
80
120
160
200
240
NUMBER OF NUCLEONS IN NUCLEUS (A)



Total Binding Energy in MeV
2000
1800
1600
1400
1200
1000
800
600
400
200
0
40
80
120
160
200
240
NUMBER OF NUCLEONS IN NUCLEUS (A)
He 4
Sn 120
U 238
U 234


Binding Energy Per Nucleon in MeV
10
9
8
7
6
5
4
3
2
1
Ca^{40}
Fe^{56}
C^{12}
He^{4}
Li^{7}
He^{3}
H^{2}
H^{1}
U^{234}
U^{238}
0
40
80
120
160
200
240
NUMBER OF NUCLEONS IN NUCLEUS (A)

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