EE 213, Microscopic Nanocharacterization of Materials
Lecture 9.
other micro-characterization using ion beams

Class website: https://ee213-winter16-01.courses.soe.ucsc.edu

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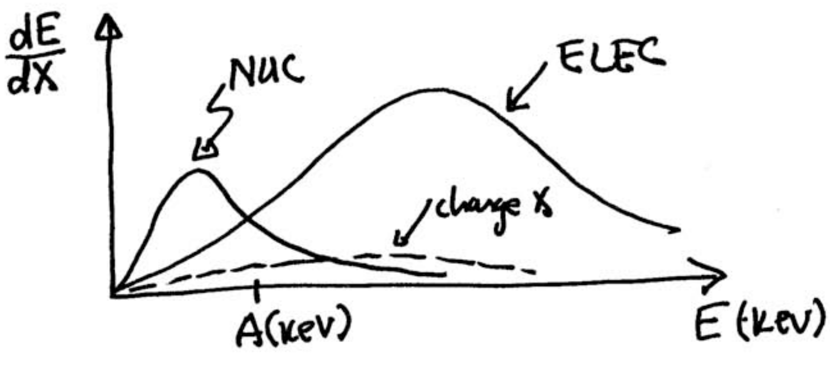
ION INTERACTIONS

three main components

1. "nuclear" energy loss, dominates at low energies when $E < A$ keV
   ↑ at.wt inc-ion

2. electronic energy loss
   interactions with atomic electrons
   (like "inelastic" electron scattering)

3. charge exchange
   $\lesssim 10\%$ of total



Ruth. Backscattering (RBS). another charged particle method

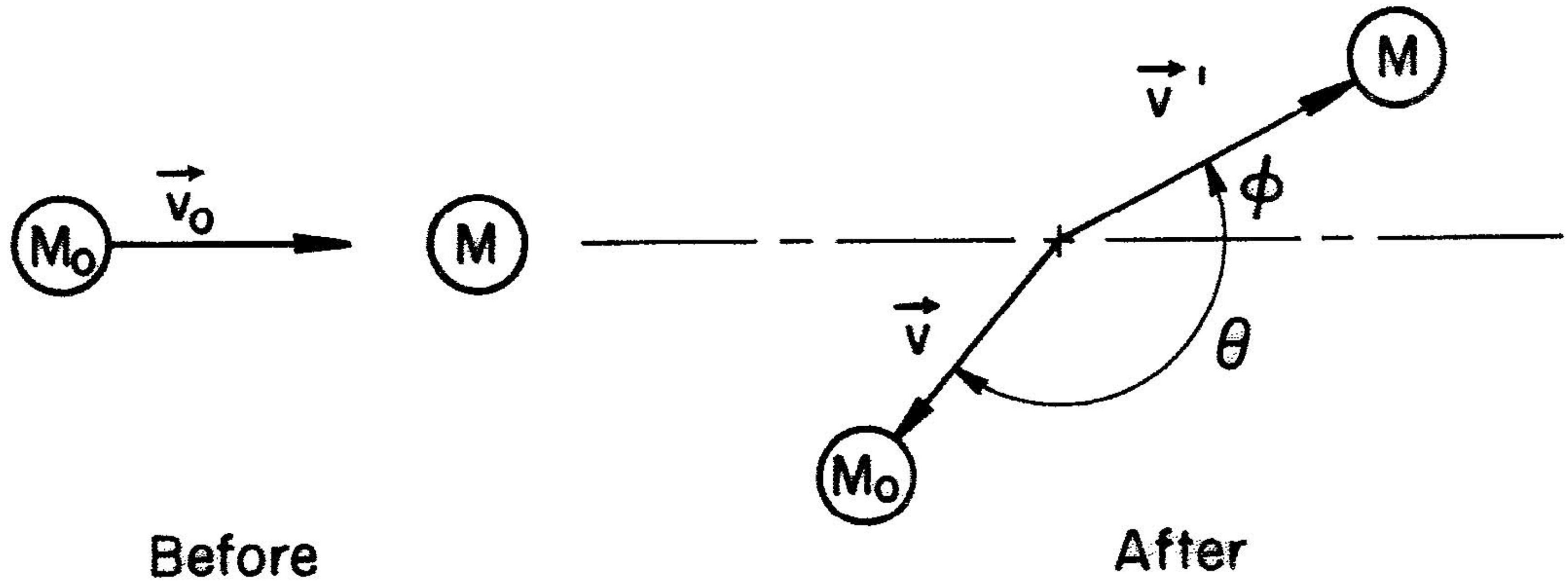
use ions that are backscattered to analyze composition

old technique / used to analyze composition of moon's surface
before Apollo 11 landed.

uses "Coulomb" scattering of fast light ions.
(main use is with mm diam beams
but new sources lead to μm type resolution)

Basis: 1) wide angle scattering between two nuclei
[Rutherford and Coulomb]
2) electronic energy losses of charged
particles on traversing a solid
(ie like inel. scattering by electrons)

energy of ions / > several 100 keV
< several MeV
So: No sputtering of material
No nuclear reactions



M_o
$\vec{v}_o$
M
M
$\vec{v}\,'$
ϕ
$\vec{v}$
θ
M_o
Before
After

Lect 9. RBS

simple kinematics /

assume $M_0 < M$
non-rel. velocities

—1) $\frac{1}{2} M_0 v_0^2 = \frac{1}{2} M_0 v^2 + \frac{1}{2} M v'^2$

inc. particle mass

target particle mass (stationary)

—2) $M_0 v_0 = M_0 v \cos\theta + M v' \cos\phi$

diag

—3) $0 = M_0 v \sin\theta + M v' \sin\phi$

solve (2), (3) for $(v')^2$
substitute into (1) gives:

$$\left(v/v_0\right) = \frac{\left[M_0 \cos\theta \pm \sqrt{M^2 - M_0^2 \sin^2\theta}\right]}{M_0 + M}$$

only + has physical meaning

energy before collision

$$\therefore \left(\frac{E_0}{E}\right) = \left(\frac{v_0}{v}\right)^2 = \frac{1}{K}$$

energy of inc. particle after collision

kinematic factor
(not sensitivity factor as in Auger, or k factor for X rays)

define $X = M_0/M < 1$ (ratio $\frac{\text{inc}}{\text{target}}$ masses)

4 Lect 9 RBS

$$\therefore \quad K = \left(\frac{v}{v_0}\right)^2 = \left[\frac{x\cos\theta + \sqrt{1 - x^2 \sin^2\theta}}{1+x}\right]^2$$

NOTE: K is INDEPENDENT of kinetic energy of incident particle
depends only on mass ratio, x
and scattering ∡ of inc. particle

If $x \ll 1$ as with electrons X = 1/1837A

then $K = 1 - \dfrac{[1-\cos\theta]}{918\,A}$ — atomic wt. of mass M (in AMU's)

NOTE: the fractional energy loss is

$$\frac{\Delta E}{E_0} = \frac{E_0 - E}{E_0} = 1 - \frac{E}{E_0} = 1 - K = \frac{1-\cos\theta}{918\,A}$$

A in amu
Au = 197
Si = 28

so for electrons this type of Coulomb scattering is essentially ELASTIC! $K \approx 1$

eg/ $e^- \rightarrow A = 200$, $\theta = 180°$ "pure backscatt"

$\Delta E/E = \dfrac{2}{918 \times 200} = 1.09 \times 10^{-5}$ // ~10 PPM

100 keV → 1 eV!
"elastic"

Si → even with Si, = 70 PPM //

for light ions incident on a target $K<1$ non-negl.

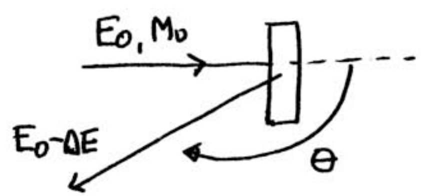
pure backscattering $\theta = 180^{\circ}$

$$\boxed{K = \left(\frac{1-x}{1+x}\right)^2}$$

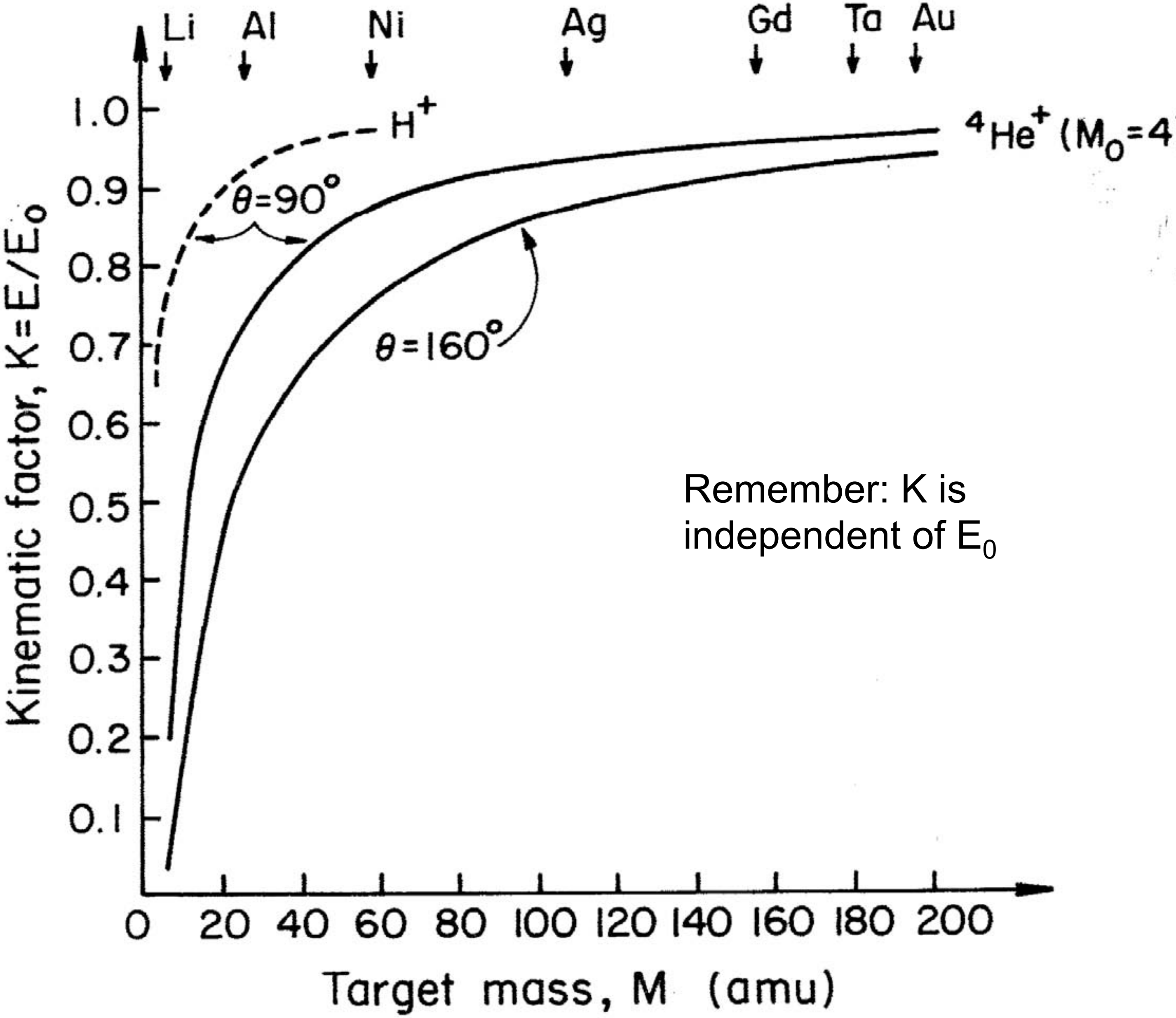
$^4He^+$ on Al (A=27) $\Longrightarrow K(\pi) = 0.8$ / 20% energy loss

$^4He^+$ on Ag (A=108) $\Longrightarrow K(\pi) = 0.94$/ 6% loss
for 2 MeV particles is 120 keV!

Thus, energy lost in a light ion, heavier atom collision is a "measure" of the target mass (if we know θ, the scatt ∡)



we exploit change of K with A for characterization



Remember: K is independent of E_0

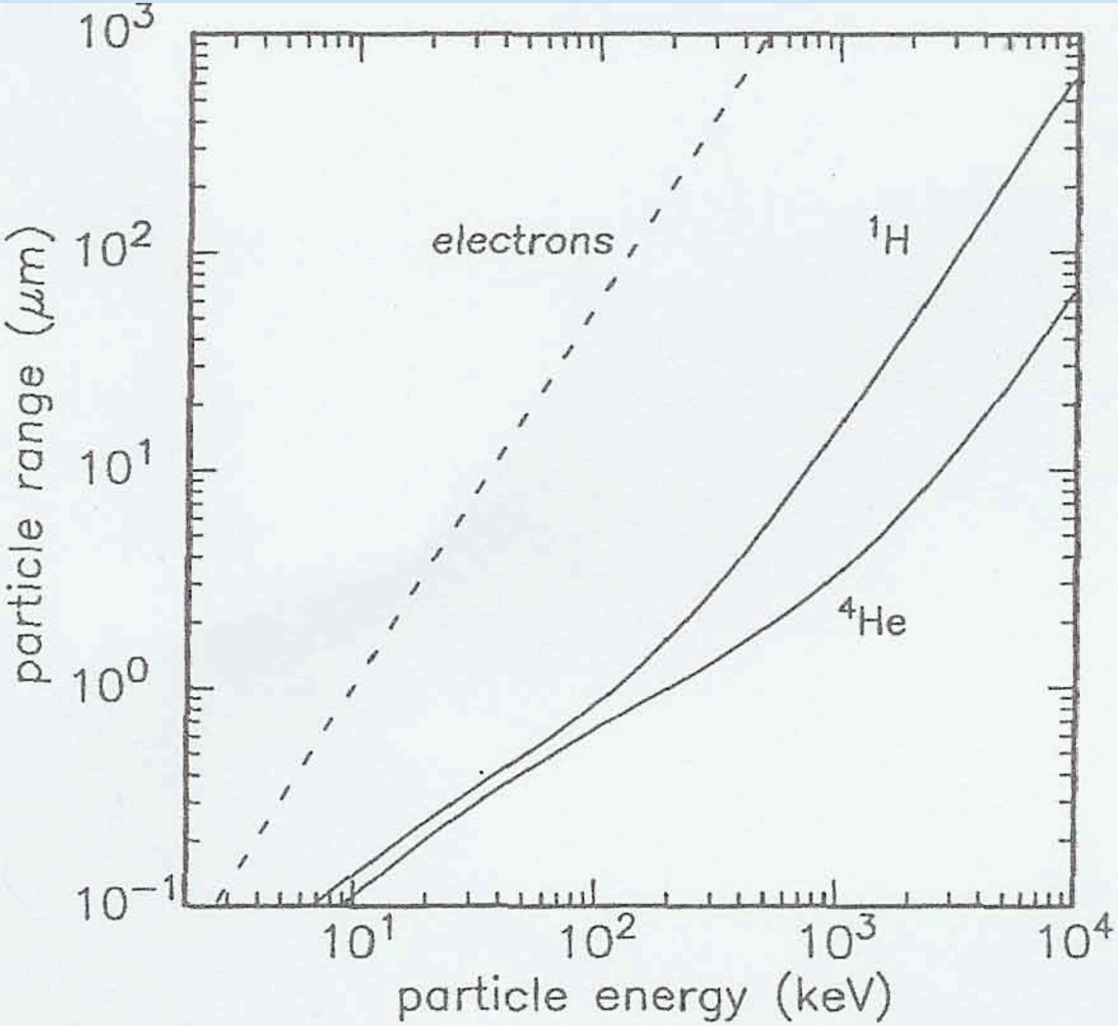
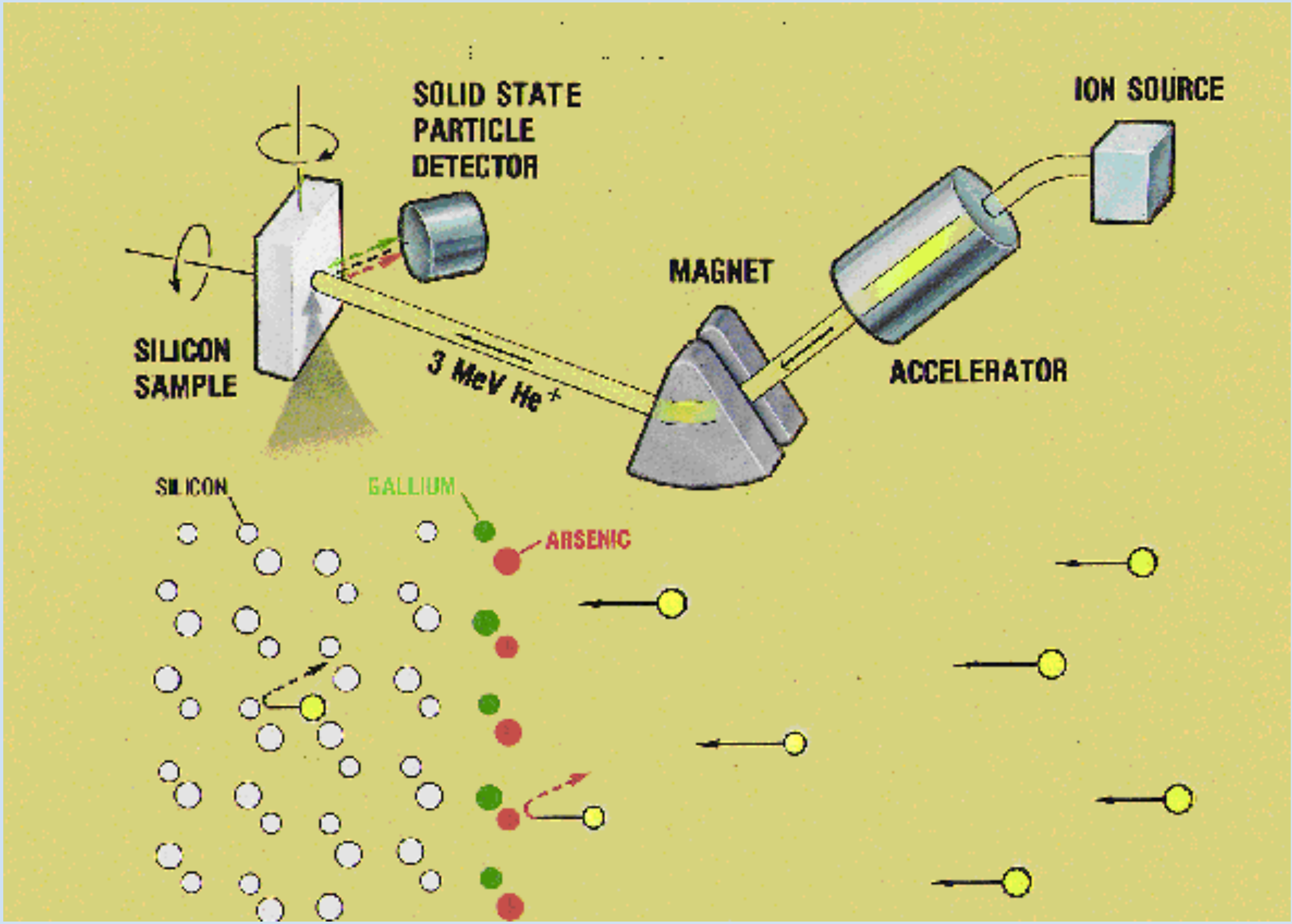


Figure 1.5. Average range of ^{1}H ions, ^{4}He ions, and electrons in amorphous silicon as a function of particle energy. The range curve for 38 keV electrons is discussed in Section 1.6.

see NIST tables.



Typical RBS set up

what about fact that target atoms are in a solid?

chem. effect negligible, binding ~ 1–10 eV << ΔE !

∴ RBS rarely gives us the chemical state of mass M ////

let's see how we would do quantitation/ atom analysis//

in Ruth. model: 2 bare nuclei
$+Z_0 e$, $+Ze$

elec screening

correct as long as incident ion can penetrate into the innermost K shell orbital so it sees full ~~ne~~ nuclear charge.

mentions nuclear reactions

ie. $E_0 > Z_0 \cdot E_K$

for $^4He^+$, $Z_0 = 2$, for Au, $E_K \cong 81$ keV
$\therefore Z_0 E_K \cong 162$ keV

using 1–2 MeV $^4He^+$ satisfies this.

actual Ruth x section (gen'l) is:

we did this only before

$$\frac{d\sigma}{d\Omega} \propto \frac{(Z_0 Z)^2}{E_0^2}\left[\frac{4\left(\cos\theta+\sqrt{1-x^2\sin^2\theta}\right)^2}{\sin^4\theta\sqrt{1-x^2\sin^2\theta}}\right]$$

where $x = M_0/M$

E. Rutherford. Phil. Mag. 21. 669 (1911)

in limit $x \ll 1$, ie electrons.

$$\boxed{\frac{d\sigma}{d\Omega} \propto \frac{(Z_0 Z)^2}{E_0^2}\frac{1}{\sin^4(\theta/2)}}$$ expression from before

∴ we use the proportionality factors from before.

and if $x < \frac{1}{2}$ we can simplify above for light ions to be:

$$\left.\frac{d\sigma}{d\Omega}\right|_R \cong \frac{12.96(Z_0 Z)^2}{E_0^2\sin^4\left(\frac{\theta}{2}\right)}\left[1-2x^2\sin^2\frac{\theta}{2}\right]$$ in $\mathring{A}^2$/ster if E_0 in eV

for $^4He^+$, θ near 180° this is only 2% different than exact expression

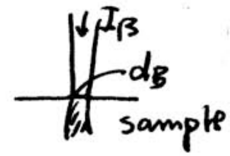
(9) cont Lect 9. RBS

call $\left[1-2X^2\sin^2\frac{\theta}{2}\right] = f_M$ the mass correction factor

then $$\boxed{\left.\frac{d\sigma}{d\Omega}\right|_R = \frac{12.96\,(Z_0 Z)^2}{E_0^2 \sin^4\left(\frac{\theta}{2}\right)} \cdot f_M}$$ in $\mathring{A}^2$, E_0 in eV

$f_m \cong 1$ if $X \ll 1$

so $$S = NJ\sigma \underbrace{Y}_{=1} F$$

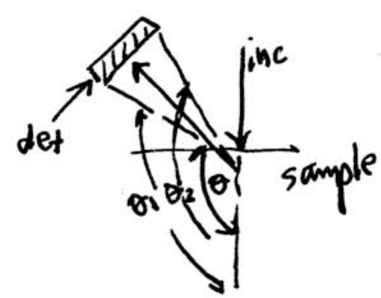


$$NJ = \frac{N I_B}{\frac{\pi}{4} d_B^2} = \underbrace{n}_{\text{\# atoms/unit area}} I_B$$

Note: current density vs beam current

$$S = n I_B \int_{\theta_1}^{\theta_2} \left.\frac{d\sigma}{d\Omega}\right|_R d\Omega$$, for MeV ions pretty much everything into detector is counted so F is just the $d\Omega$ term

talk abt detectors



(10) cont Lect 9. RBS

what is detector?

same as for Xrays – SS detectors
measure energy by # eh pairs created –

whats the energy resolution?

$\Delta E = 1.6\sqrt{E}$ in eV for Si

neglects elec noise, straggling

$\therefore$ for 1 MeV, $\Delta E = \underline{\underline{1.6\,keV}} \Longrightarrow \frac{\Delta E}{E} = 1.6\times10^{-3}$ energy resolution //

look at K curves to see that ..

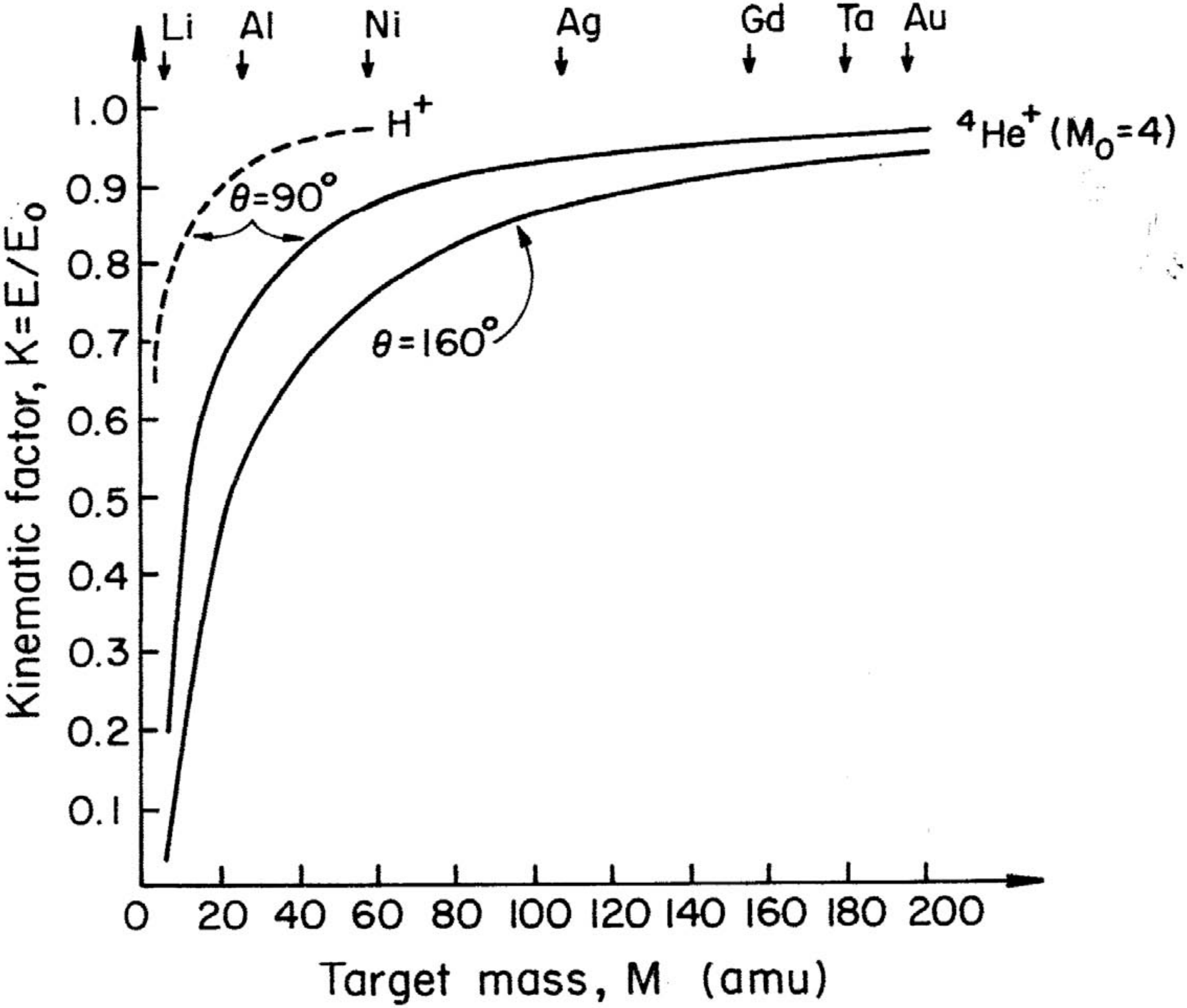
this is enough to distinguish diff atoms!

· solid ∡ of collection is small (like for ebeam xray)
since we have to get ions in

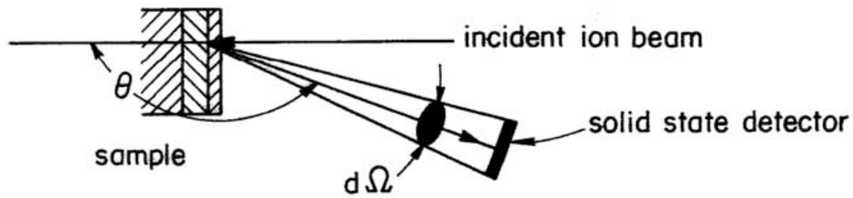
typically < 1° //

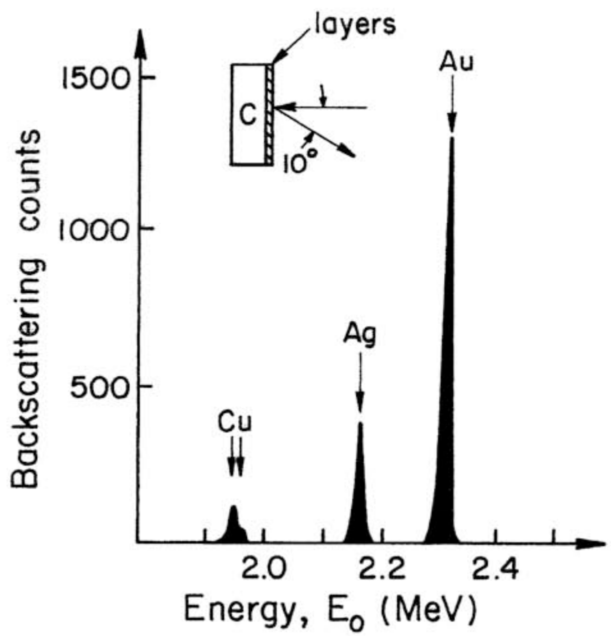
$\therefore \left.\frac{d\sigma}{d\Omega}\right|_R$ ~ constant over detector

$\therefore \quad S = n I_B \left.\frac{d\sigma}{d\Omega}\right|_R^{AVG} \cdot d\Omega$



Li
Al
Ni
Ag
Gd
Ta
Au
H+
$^4He^+$ (M_0=4)
θ=90°
θ=160°
Kinematic factor, K=E/E_0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0 20 40 60 80 100 120 140 160 180 200
Target mass, M (amu)





monolayers

Nicolet et al.

Science. 177. 841 (1972)

spectrum of 2 MeV $^4He^+$ ions backscattered at 170° from monolayers on carbon substrate

(11) cont Lect 9

$\therefore$ we can write the signal as $P = S\tau$

$$P = n I_B \tau \left(\frac{d\sigma}{d\Omega}\right)_R^{AVG} \cdot d\Omega$$

show exp // doc cam

for the conditions,

$I_B = 17\,n\,Amps$, $d\Omega = 4.12 \times 10^{-3}$ steradian, $\tau = 17$ min.

$E_0 = 3\,MeV$ ${}^4He^+$ $\qquad \theta = 170^\circ$

Z He = 2 /

we get $P = n \times 4.285 \times 10^{11} \left(\frac{d\sigma}{d\Omega}\right)_R$ cts

$\phi_B = 1\,mm$ //

now taking into account the mass corrections

$I_B\tau$ generally given in coulombs

$$f_A = 1 - 2\left(\frac{M_{He}}{A}\right)^2 \sin^2\frac{\theta}{2} \quad \text{for } \theta = 170^\circ$$

$$\boxed{f_A = 1 - \frac{31.76}{M_A^2}}$$

$M_A = A$ in AMU's

$$P = n \times 4.285 \times 10^{11}\left[\frac{12.96\,(Z_0 Z)^2}{E_0^2 \sin^4\frac{\theta}{2}}\right] f_A$$

$$P(cts) = n \times 5.64\, Z^2 \left[1 - 31.76/M^2\right]$$

#/unit area = # / Å²

assume $n \cong .1$ atom/Å² (good to 10%)

cont

element	Z	A	P(cts) calc.	P(cts) measured
copper	29	63.6	473	460
silver	47	107.9	1246	1223
gold	79	197.0	3520	3960

isotopes in Cu

so how sensitive is RBS.

peaks ~ 20keV wide // 2-5 keV/channel

assume you need min 10 cts // (ie 1-4 cts/ch)

then for Au / $\frac{10}{3960} = 2.5 \times 10^{-3}$ monolayer //

but $d_B = 1mm \Longrightarrow$ 1 monolayer ~ 10^{13} atoms !

reduce $d_B \Longrightarrow 1\mu m$ then 1 monolayer ~ 10^7 atoms //

but under same time counting time only 4×10^{-3} cts

GE —

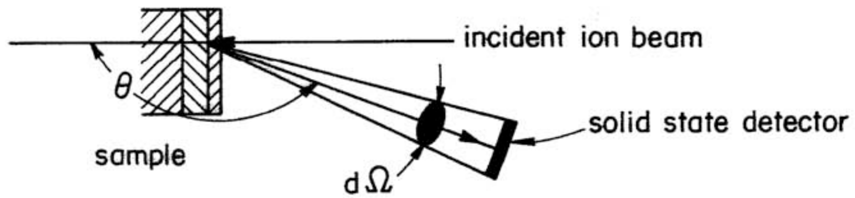
Osaka —

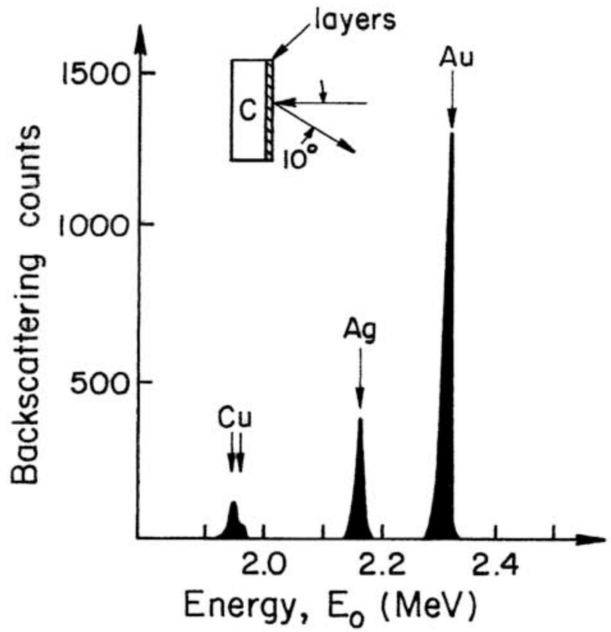
so need much brighter source

liquid metal or Field ionization sources

later/

— get 3-6 orders of magnitude ~~mo~~ more current //





monolayers

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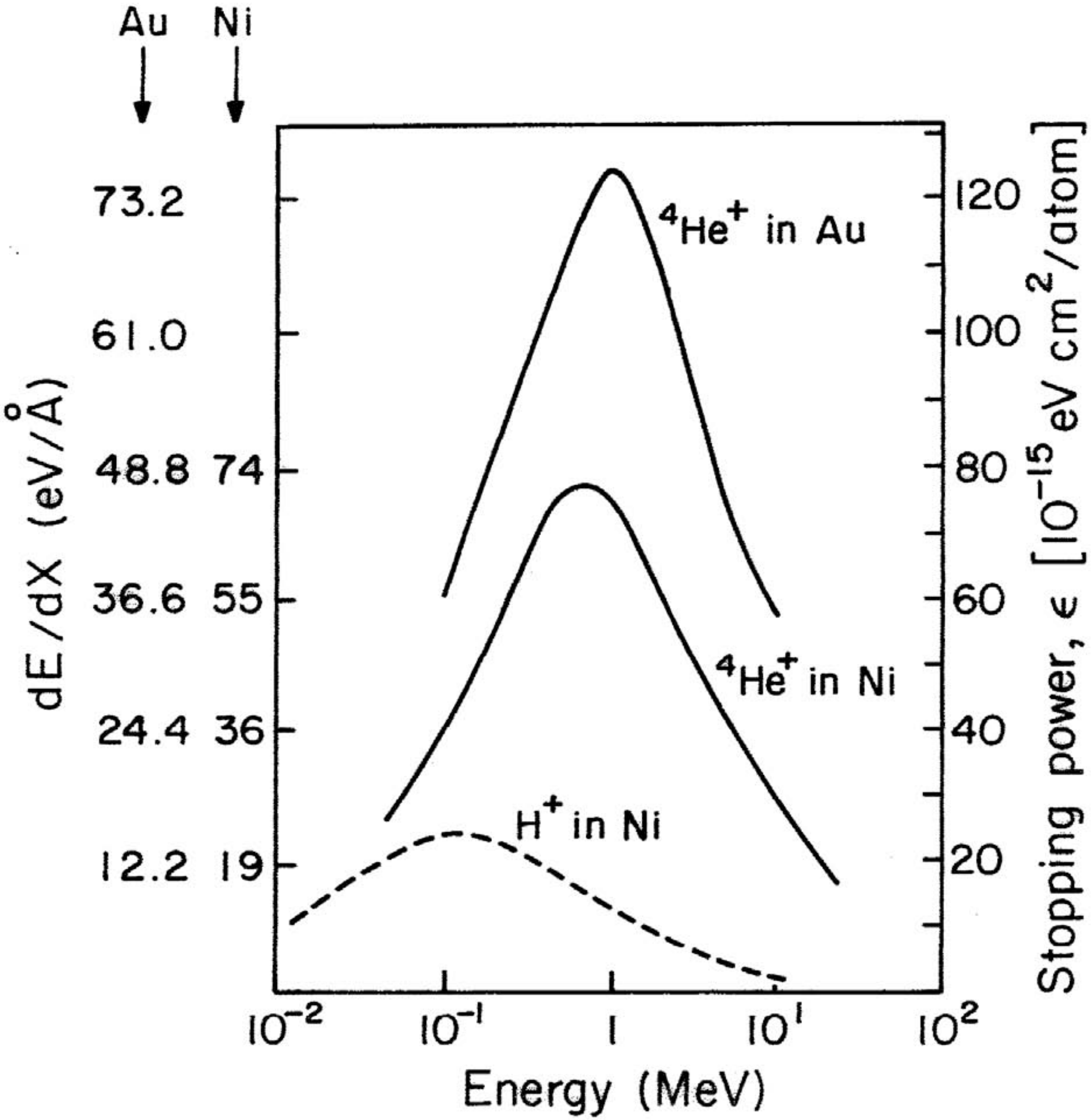


after Ziegler, Andersen

(15) unit EE213 / Lect 9 RBS

depth discrimination using RBS

possible because light ions lose energy in known way (remember electrons) —

we consider only "electronic energy loss" (same as for electrons — interact with atomic electrons)

note/ sputtering at low keV // later

this is expressed as:

stopping power: $\frac{dE}{dX}$ energy lost/collisions length

elec. stopping power

usually defined as a ~~stopping~~ stopping power/atom density

$$\varepsilon = \frac{1}{n}\frac{dE}{dX}$$ units energy cm^2/atom //

atom density

what was $\frac{dE}{dx}$ for elec

typical values for $^4He^+$ in .1-2 MeV range

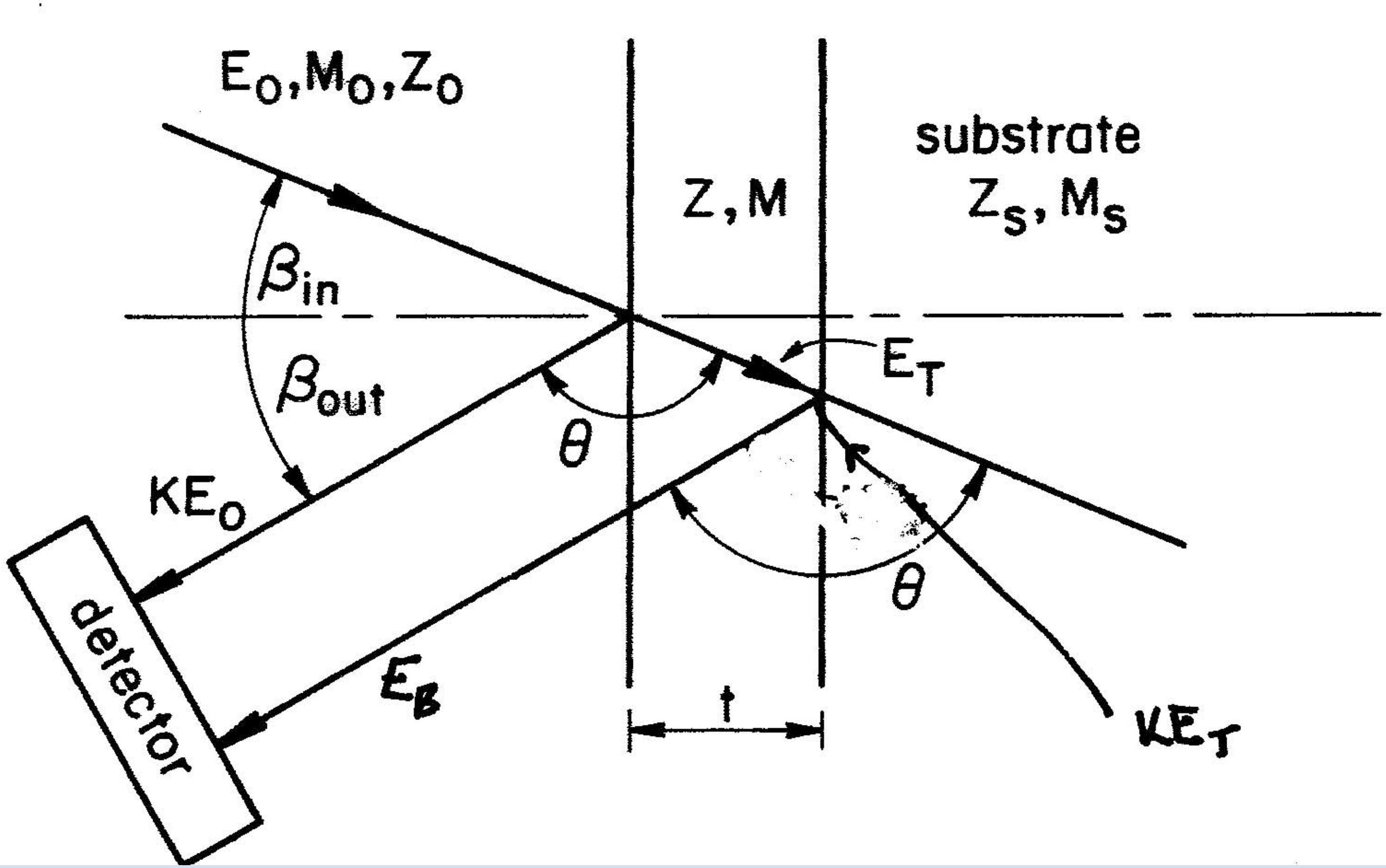
are $\sim$ 50 eV/Å or 100×10^{-15} ev cm^2/atom || solids

see px | doc cam

these ions don't go very far in material | RBS limit for solids. ~ microns //

show α particles in air

note peak for given E_o


E_0, M_0, Z_0
substrate
Z, M
Z_S, M_S
β_{in}
β_{out}
E_T
θ
θ
KE_0
detector
E_B
t
KE_T

unit EE2B / Lect 9   RBS.

look at RBS geometry to see how we get depth discrimination –

assume $Z > Z_s$

$Z_0 < Z, Z_s$

what will we detect in backscattering?

1. Front Surface Scatt.

if backscatt there, $E_F = KE_0$ ("elastic")

NOTE/ since K only depends on M_0, M we can determine if M in surface or not!

if beneath surface. $\underline{E_F < KE_0}$

2. <u>Back surface Scatt</u> (at some depth)

energy of particle before being backscattered, E_t

$E_t < E_0$ since $\frac{dE}{dx}$ from front surface

$$\boxed{E_t = E_0 - \int_0^{t/\cos\theta_{IN}} \frac{dE}{dx} dx}$$

it loses energy again on its way out,

so final energy detected, E_B is:

cont EE 213/ lect 9 RBS

$$E_B = \underbrace{KE_t}_{\text{energy after the backscattered event}} - \underbrace{\int_0^{t/\cos\theta_{out}} \frac{dE}{dx}\,dx}_{\text{energy lost on the way out}}$$

∴ energy diff. between those particles scattered from front and at a depth t is:

$$\Delta E = \underbrace{KE_0}_{\text{front}} - \underbrace{E_B}_{\text{at depth } t}$$

$$\Delta E = KE_0 - KE_t - \int_0^{t/\cos\theta_{out}} \frac{dE}{dx}\,dx$$

$$= KE_0 - \left[K\left(E_0 - \int_0^{t/\cos\theta_{in}} \frac{dE}{dx}\,dx\right)\right] - \int_0^{t/\cos\theta_{out}} \frac{dE}{dx}\,dx$$

$$\underline{\Delta E = K\int_0^{t/\cos\theta_{in}} \frac{dE}{dx}\,dx + \int_0^{t/\cos\theta_{out}} \frac{dE}{dx}\,dx}$$

thus, overlayer thickness t, related to ΔE //

cont

usually $\theta_{IN}, \theta_{OUT} \lesssim 10-20°$

and $\frac{dE}{dx}$ slow varying functions of energy

show dE/dx curves

(choose E_0 near max of $\frac{dE}{dx}$ curves)

and it only changes drastically near path end.

$$\therefore \int_0^{*} \frac{dE}{dx} dx \cong t \left(\frac{dE}{dx}\right)_{AVG} \quad \text{to a few \% —}$$

$$\therefore \Delta E = t \underbrace{\left[K \left(\frac{dE}{dx}\right)_{IN}^{AVG} \frac{1}{\cos\theta_{IN}} + \left(\frac{dE}{dx}\right)_{OUT}^{AVG} \frac{1}{\cos\theta_{out}} \right]}$$

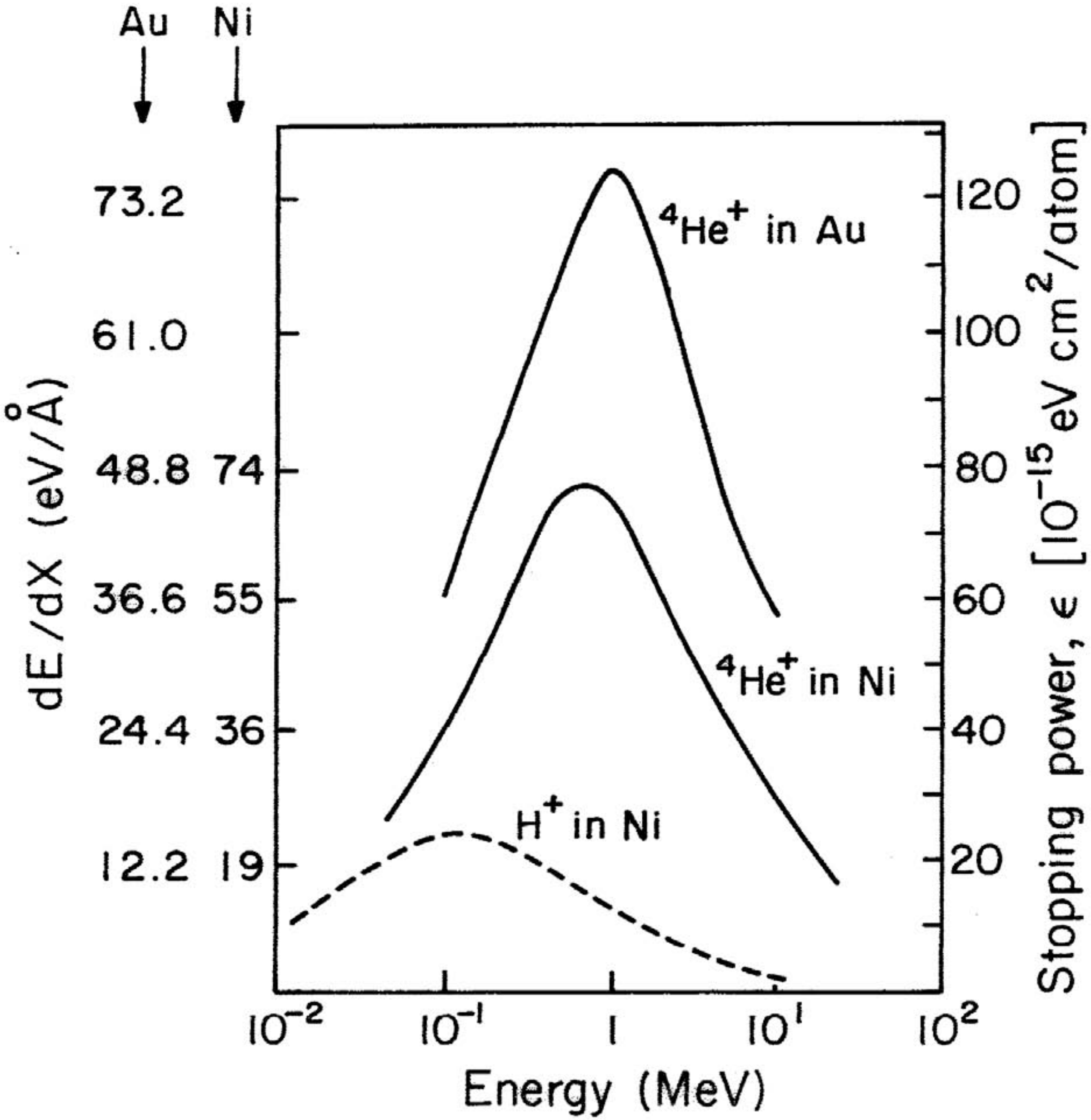
$= [S]$, the energy loss factor
(not signal or stopping power)

NOTE / $[S]$ depends on the backscatt. atom thru K and the matrix thru dE/dx

$$\therefore \boxed{t = \frac{\Delta E}{[S]}}$$

overlayer thickness related to energy diff.

if we write the stopping power as $\mathcal{E} = \frac{1}{n} \frac{dE}{dx}$
atom density



after Ziegler, Andersen

usually $\theta_{IN}, \theta_{OUT} \lesssim 10-20°$

and $\frac{dE}{dx}$ slow varying functions of energy

show dE/dx curves

(choose E_0 near max of $\frac{dE}{dx}$ curves)

and it only changes drastically near path end.

$\therefore \int_0^{t} \frac{dE}{dx} dx \cong t \left(\frac{dE}{dx}\right)_{AVG}$ to a few % —

$$\therefore \Delta E = t \underbrace{\left[K \left(\frac{dE}{dx}\right)_{IN}^{AVG} \frac{1}{\cos\theta_{IN}} + \left(\frac{dE}{dx}\right)_{OUT}^{AVG} \frac{1}{\cos\theta_{out}} \right]}_{= [S]}$$

$= [S]$, the energy loss factor

(not signal or stopping power)

NOTE/ $[S]$ depends on the backscatt. atom thru K and the matrix thru dE/dx

$\therefore \boxed{t = \frac{\Delta E}{[S]}}$ overlayer thickness related to energy diff.

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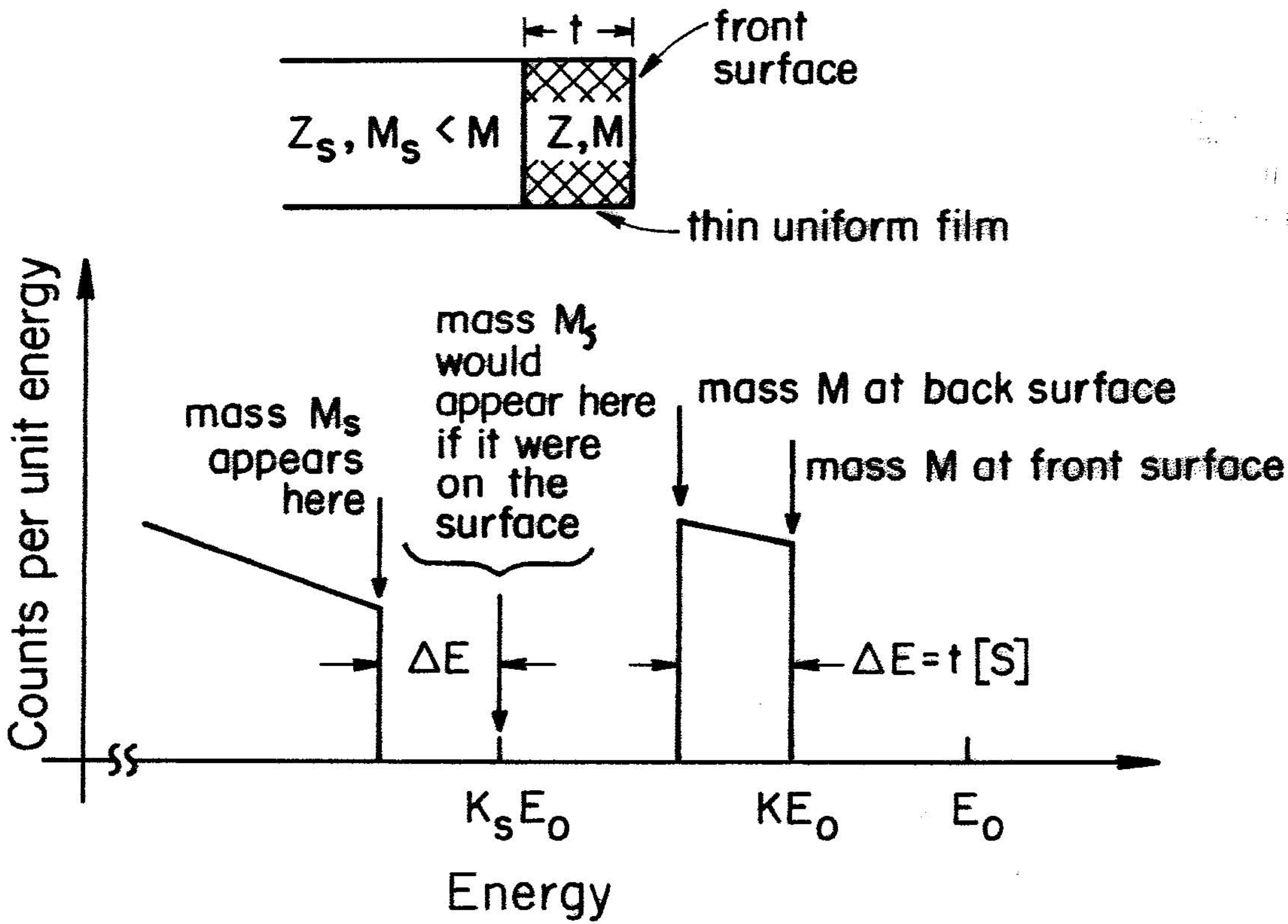

t
front surface
$Z_s, M_s < M$
Z,M
thin uniform film
Counts per unit energy
mass M_s appears here
mass M_s would appear here if it were on the surface
mass M at back surface
mass M at front surface
ΔE
ΔE = t [S]
K_sE_o
KE_o
E_o
Energy

then $[S] = n\left[K(\varepsilon)_{IN}\frac{1}{\cos\beta_{IN}} + (\varepsilon)_{OUT}\frac{1}{\cos\beta_{out}}\right]$

$\therefore \boxed{\Delta E = nt[\sim]}$

#/area.

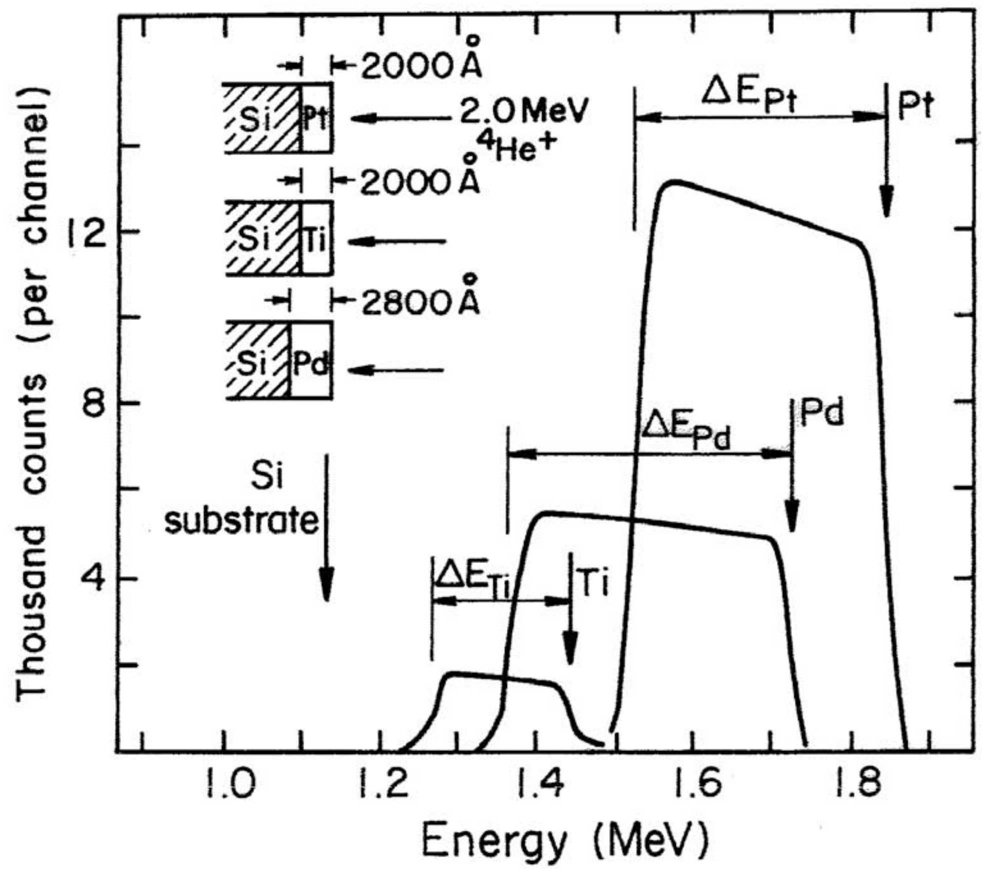
since $[\sim]$ depends upon material

$\Delta E/t$ is diff. for different material

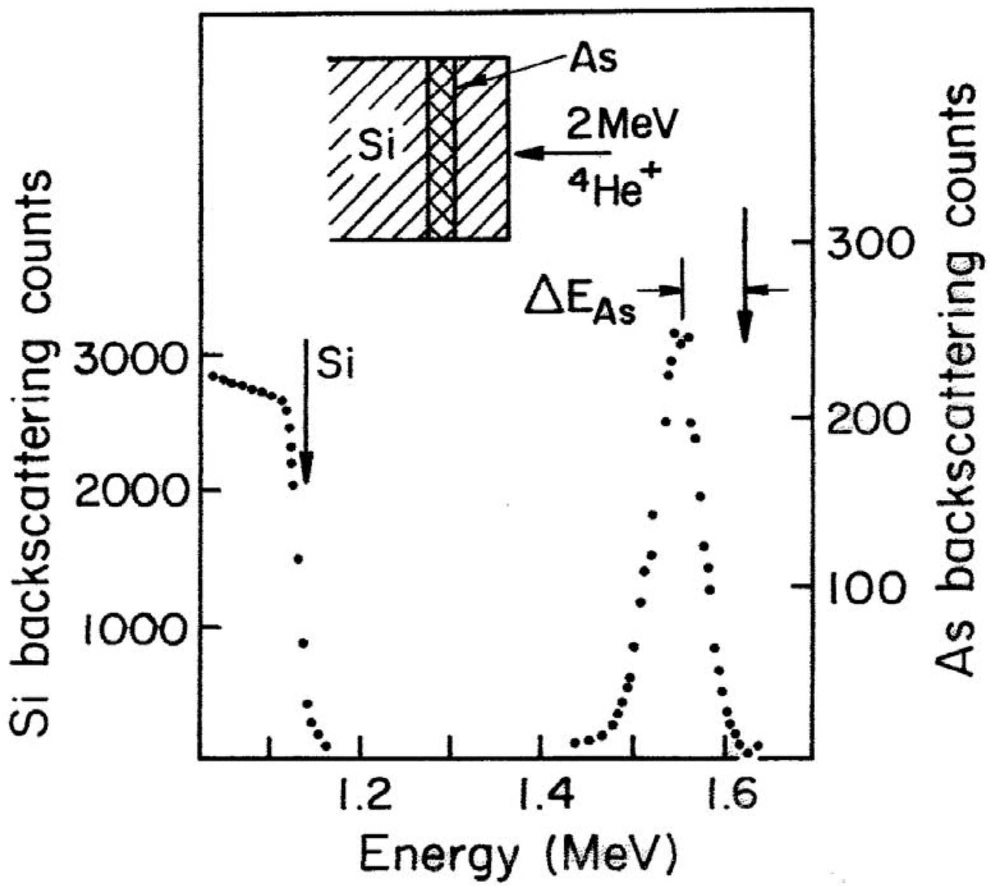
the thickness or depth scale is different for different materials

NOTE/ can only get t if we know atom density of overlayer

element	Z	$\Delta E/t$ (MeV/cm)	$\frac{\Delta E}{nt}$ (MeV cm²)
Pt	78	1.615×10^4	23.4×10^{-20}
Pd	46	1.293×10^4	18.2×10^{-20}
Ti	22	0.88×10^4	14.9×10^{-20}



position of vertical arrows indicate
energy of the backscattered ions scattered
off the front surface [$E = KE_0$]
2 MeV $^4He^+$ inc. ions



$\theta_{OUT} = 170°$

vertical arrows mark energy of ions scattered off Si and As atoms on the surface

Nicolet et al (1978)

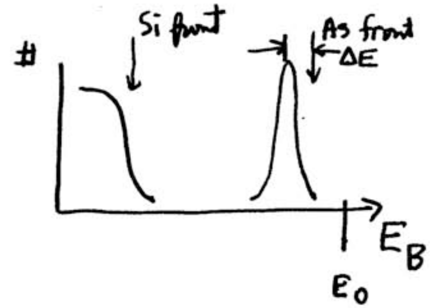
24
23

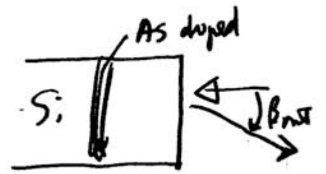
unit Lect #9. EE213 - RBS

So lets see how we determine depth of some material within a substrate.

< MA Nicolet et al (1978) in Backscattering Spectrometry and Related Analytical Techniques. eds JP Thomas & A Cachard (Plenum) 581-630 >

show pix





shift of As peak by 68 keV //

means its beneath surface by $t = \dfrac{\Delta E_{As}}{[S]_{As}^{Si}}$ ← energy loss factor for scattering off As atoms in Si

$$[S]_{As}^{Si} = K_{As}\left(\frac{dE}{dx}\right)_{IN}^{Si} + \frac{1}{\cos 10^\circ}\left[\frac{dE}{dx}\right]_{OUT}^{Si}$$

$$= n_{Si}\left[K_{As}\varepsilon_{IN}^{Si} + 1.0154\,\varepsilon_{out}^{Si}\right]$$, $n_{Si} = .052$ atoms$/Å^3$

(As is a dopant so essentially all Si)

25 JF Ziegler (1977) He Stopping Power and Ranges in All Elemental Matter (Pergamon Press NY)
also NIST web site

NIST tables

unit Lect #9. EE 213 RBS

Surf. Energy Approx

assume ΔE in reaching depth t is small

then $\varepsilon_{IN}^{Si} \cong \varepsilon_{IN}^{Si}(E_0)$ at the surface.

and $\varepsilon_{OUT}^{Si} \cong \varepsilon_{OUT}^{Si}(K_{As}E_0)$ / generally OK, $t \ll 1\mu$

look up in tables / $K_{As}\varepsilon_{IN}^{Si}(E_0) = \underbrace{.8135}_{K_{As}} \times 49.3 \times 10^{-15} \frac{eV\,cm^2}{atom}$

As $Z=33$, $A=75$

$\varepsilon_{OUT}^{Si}(.8135 E_0) = \underbrace{1.0154}_{1/\cos\theta_{OUT}} \times 56 \times 10^{-15} \frac{eV\,cm^2}{atom}$

$\therefore [S]_{As}^{Si} = 4.99 \times 10^9$ eV/cm

$\therefore t_{As} = \frac{\Delta E_{As}}{[S]_{As}^{Si}} = \frac{68 \times 10^3 eV}{4.99 \times 10^9 eV/cm} = 1.363 \times 10^{-5}$ cm

$\boxed{t_{As} \sim 1400\,Å}$

since depth scale is approx. linear over small ΔE range

energy distrib of As peak directly

related to As distrib. profile

cont Lect #9. EE 213 RBS.

CAUTION !!

horizontal "energy" scale is both

— a mass scale
— a depth scale

goto plot of kinematic factors

SO !! a lighter mass atoms on surface could be mistaken for a heavy atoms beneath the surface.

(because $K_{light} < K_{heavy}$)

how to distinguish the two cases?

1. change incident ion energy
2. change the scattering ∡ (which changes K, S)

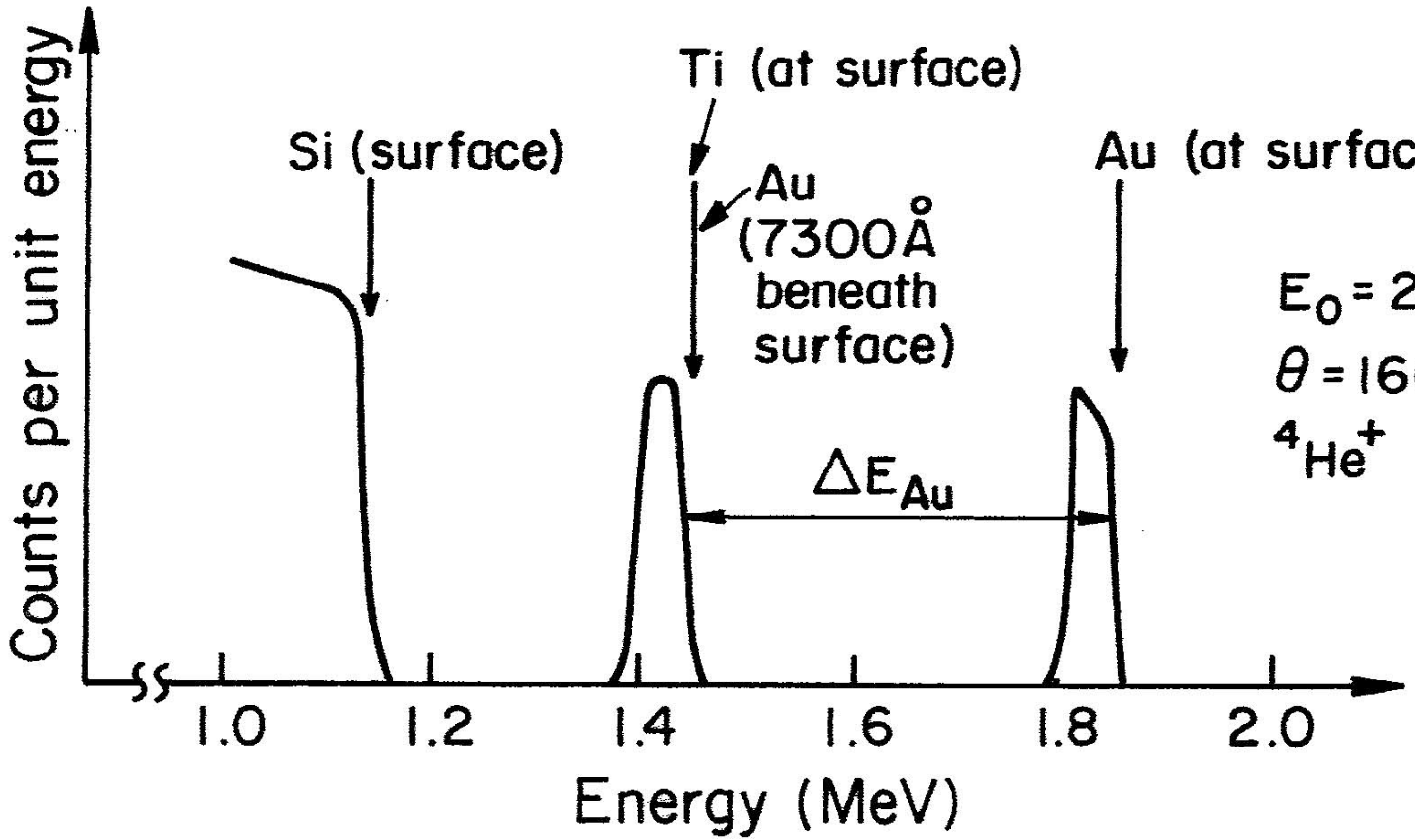
depth resolution limited by detector energy resolution and "straggling" due to statistical nature of elns. / gets worse deeper into sample.
and inc beam energy fluctuations (when using a Van der Graff accelerator)

det res 2 MeV → 1.6 keV

all the rest make $\Delta E \sim 10-20$ keV !!

∴ if $\frac{dE}{dX} \sim 50-100$ eV/Å 1-2 MeV $^4He^+$ ions

depth res. $\Delta X = \frac{\Delta E}{[S]} \simeq \frac{\Delta E}{2\,dE/dX} \approx 100-200$ Å



Counts per unit energy
Ti (at surface)
Si (surface)
Au (at surface)
Au (7300Å beneath surface)
E0 = 2 MeV
θ = 160°
4He+
ΔE Au
1.0
1.2
1.4
1.6
1.8
2.0
Energy (MeV)

(28) Lect #9 EE 213 RBS

Back to quantitation

$$P = S\tau = \eta I_B \tau \left(\frac{d\sigma}{d\Omega}\right)_R d\Omega$$

$$\frac{\eta_A}{\eta_B} = \frac{P_A}{B_B} \frac{(d\sigma/d\Omega)_B}{(d\sigma/d\Omega)_A}$$

$I_B \tau$ drops out since simultaneous measurements
same with $d\Omega$

add in mass correction factor $f_{MA} = \left[1 - 2\left(\frac{M_b}{M_A} \sin\frac{\theta}{2}\right)^2\right]$

~~or~~ and $\frac{d\sigma}{d\Omega} \propto \frac{Z^2}{E^2}$ then

our "sensitivity factor"

$$\frac{\eta_A}{\eta_B} = \frac{P_A}{P_B}\left[\left(\frac{Z_B}{Z_A}\right)^2 \left(\frac{E_A}{E_B}\right)^2 \left(\frac{f_{MB}}{f_{MA}}\right)\right]$$

assume det eff are the same.

E_A is ~~on~~ ion energy just before scattering by atom A

if A & B are at same depth, $E_A = E_B$

$f_{MB}/f_{MA} \sim 1$ to 10-20% generally.

if atoms are at different depths then $E_A \neq E_B$

(29)

cont Lect #9 EE 213 RBS

atoms at diff depths / gen'l case

$$\frac{E_A}{E_B} = \frac{E_0 - \frac{n t_A}{\cos\beta_{IN}}\,\varepsilon_{IN}^{A}}{E_0 - \frac{n t_B}{\cos\beta_{IN}}\,\varepsilon_{IN}^{B}} \quad , \quad \varepsilon = \frac{1}{n}\frac{dE}{dX}$$

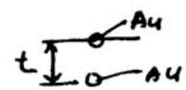
atom density of composite material which we may not know.

∴ depth corrections for quantitation becomes:

$$\left(\frac{E_A}{E_B}\right)^2 \Longrightarrow \frac{f_{tA}}{f_{tB}} = \left[\frac{E_0 - \frac{n t_A}{\cos\beta_{IN}}\,\varepsilon_{IN}^{A}}{E_0 - \frac{n t_B}{\cos\beta_{IN}}\,\varepsilon_{IN}^{B}}\right]^2$$

$$\therefore \boxed{\frac{n_A}{n_B} = \frac{P_A}{P_B}\left(\frac{Z_B}{Z_A}\right)^2 \underbrace{\left(\frac{f_{tA}}{f_{tB}}\right)}_{\text{depth correction}}\underbrace{\left(\frac{f_{mB}}{f_{mA}}\right)}_{\text{mass corrections}}}$$

example: depth corr.



$\beta_{IN} = 0$

$t = 300\,nm$

2 MeV, $^4He^+$ // $(dE/dX)_{IN} \cong 65\,eV/Å$

$$E_0 - \frac{nt}{\cos\beta_{in}}\varepsilon_{in}^{A} = 2\,MeV - .195\,MeV = 1.805\,MeV$$

$$\therefore \frac{f_t(Au)}{f_t(Au\,surf)} = \left(\frac{1.805}{2}\right)^2 = \underline{.815} \qquad 18\%$$

quant. eqn's solved by iteration

since depth correction depends on stopping power, density and dist atoms from surf.

eg/ 1. use $E_A = E_B$ approx. get estimate $\frac{n_A}{n_B}$

2. use that to get estimate of material density. n_{guess}

3. use n_{guess} to estimate t_A, t_B from shift of peaks in spectrum $\left(t = \frac{\Delta E}{[S]} \right.$

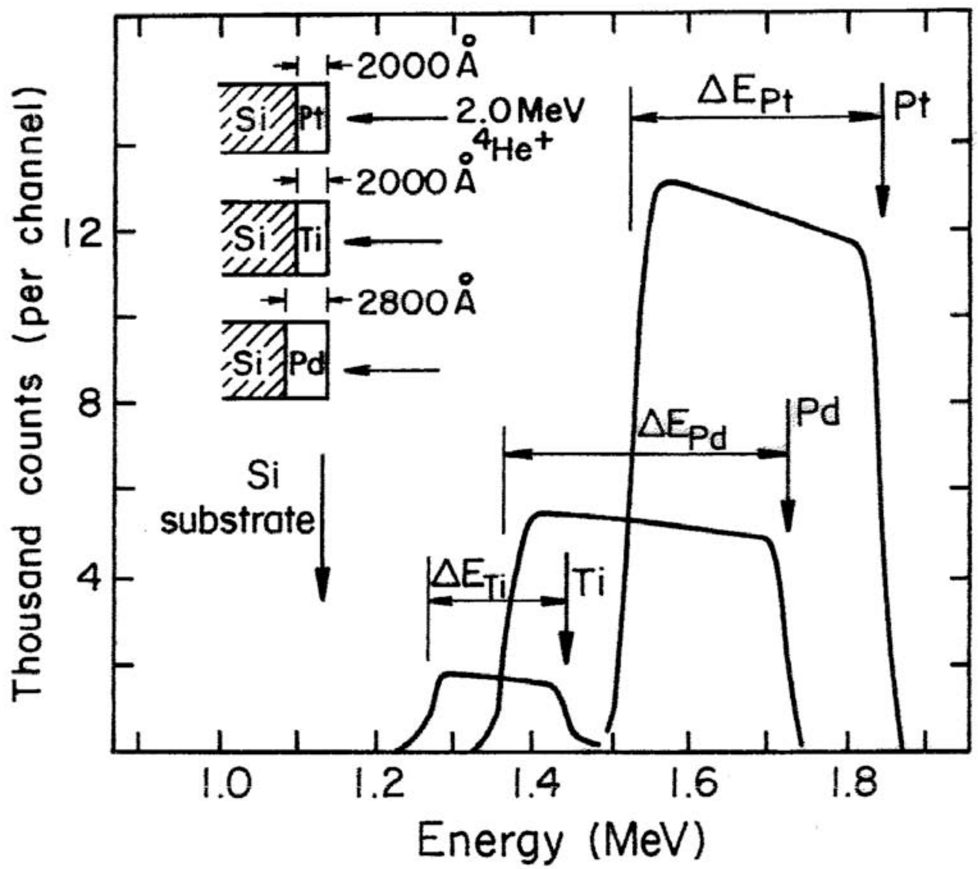
4. with these t_A, t_B, n_{guess} get new depth correction ~~fac~~ $\rightarrow$ new n_A, n_B

etc.. till convergence

L. Doolittle. Nucl Inst 3 Meth in Phys Res Sect B; Beam Interactions with Materials 3 Atoms. 9(3). 1985: 344-351

Algorithm for simulating RBS

LC Feldman 3 JW Mayer. Fund of Surf 3 Thin Film Anal. North-Holland NY 1986



position of vertical arrows indicate
energy of the backscattered ions scattered
off the front surface [$E = KE_0$]
2 MeV $^4He^+$ inc. ions

ASIDE // we assumed rect. peaks
actually they are sloped linearly

what to use for peak ht?

why?

remember Ruth x-section:

$$\left.\frac{d\sigma}{d\Omega}\right|_R \propto \frac{1}{E_0^2}$$

as ion goes into solid, it loses energy so $E(x) = E_0 - \Delta E(x)$

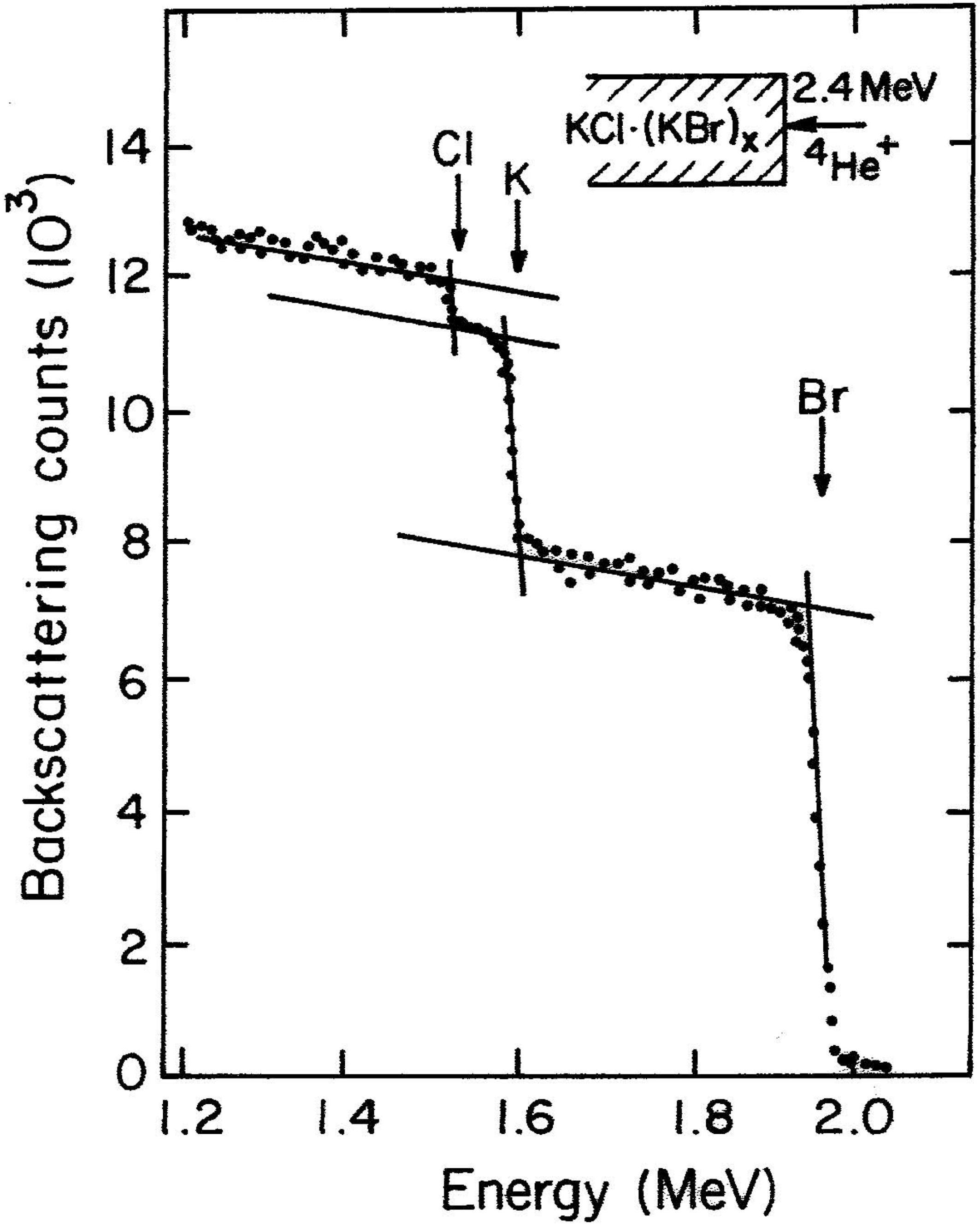
$$E(x) = E_0\left[1 - \frac{\frac{dE}{dx}\cdot x}{E_0}\right]$$ assuming minimal inc.

for small ΔE, $\frac{dE}{dx} x \ll E_0$

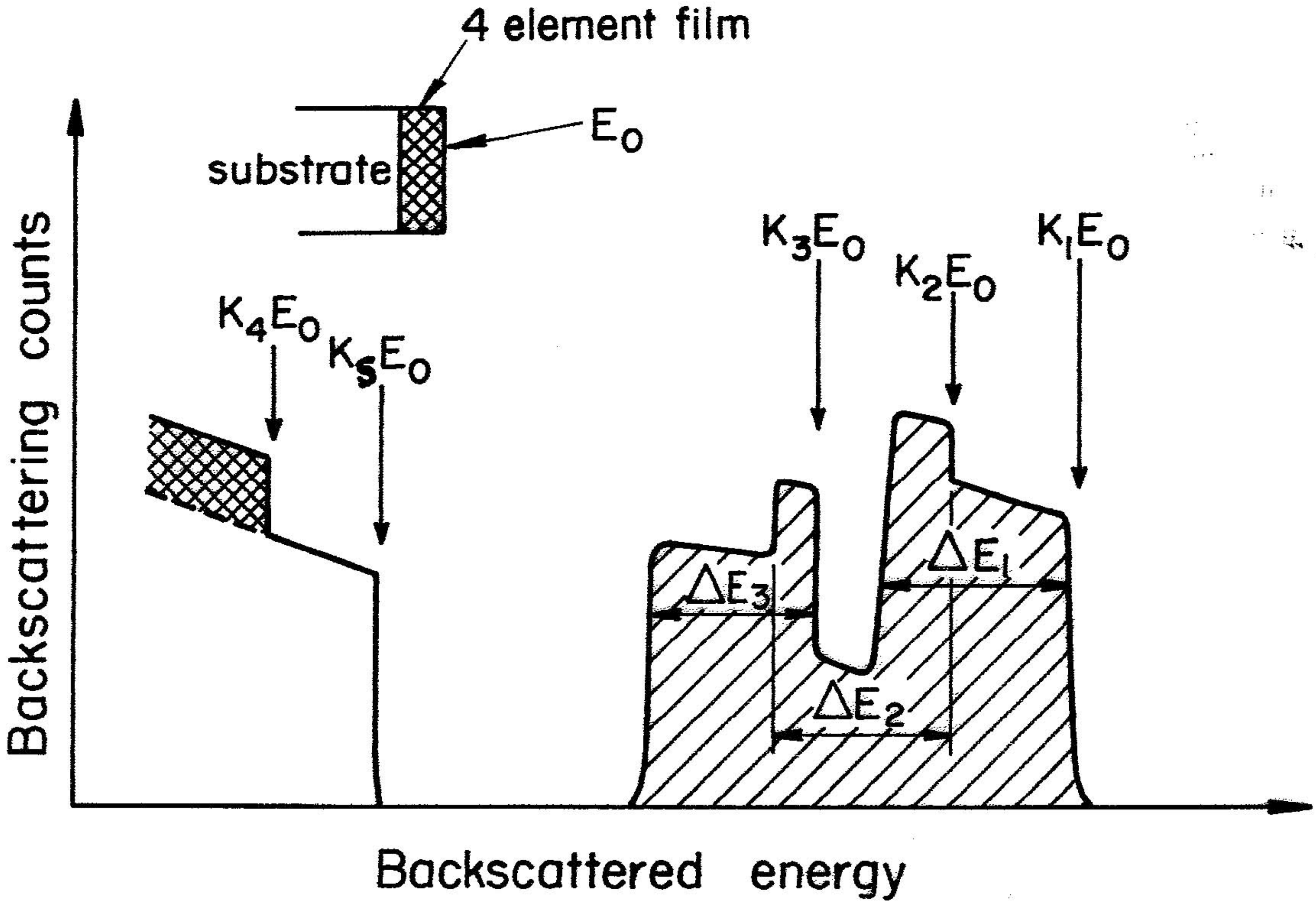
$$\left.\frac{d\sigma}{d\Omega}\right|_R \propto \frac{1}{E(x)^2} = \frac{1}{E_0^2\left[1 - \frac{(dE/dx)x}{E_0}\right]^2}$$

$$\cong \frac{1}{E_0^2}\left[1 + 2\frac{dE}{dx}\cdot\frac{x}{E_0} + \cdots\right]$$

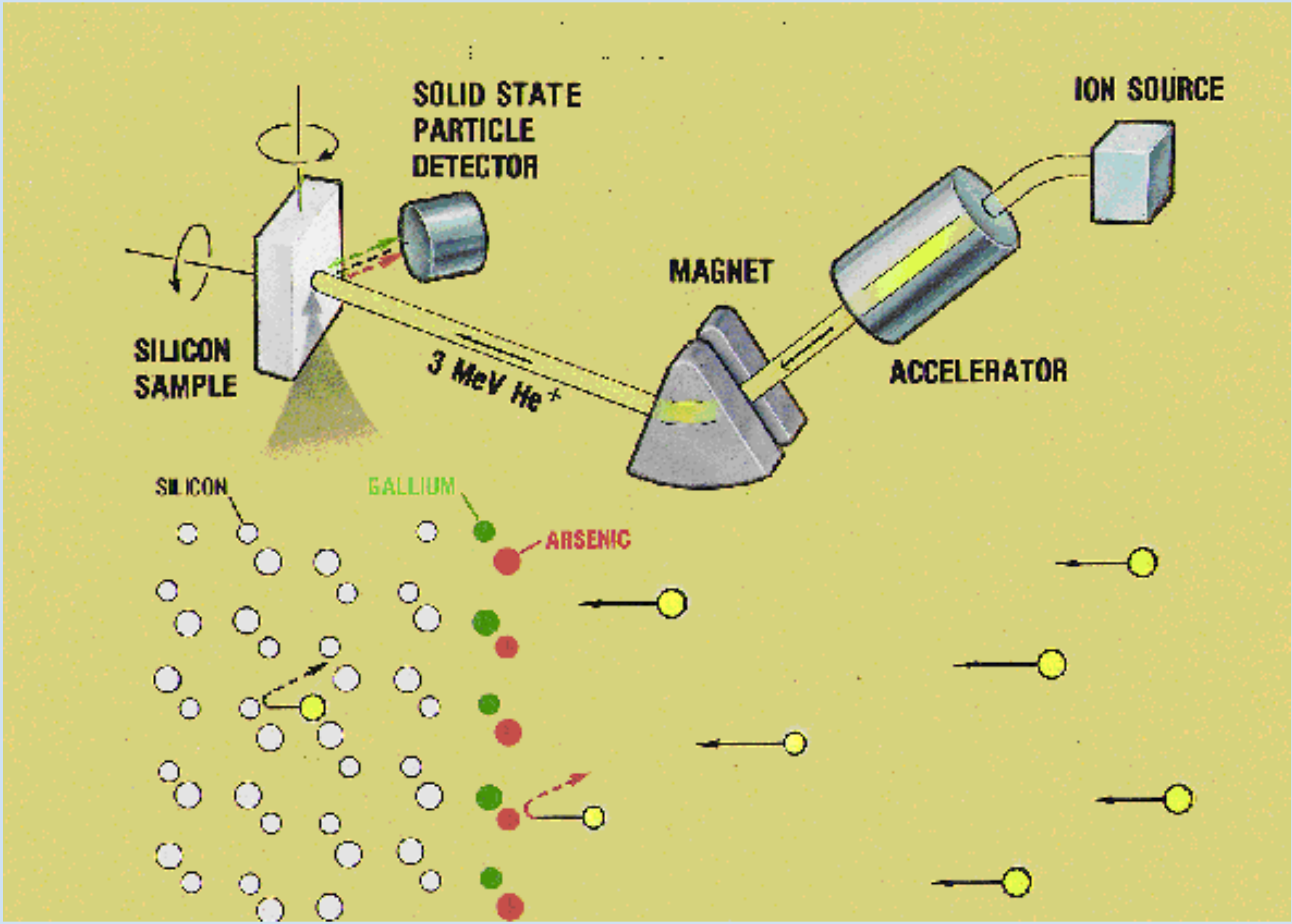
which increases linearly as you go into sample



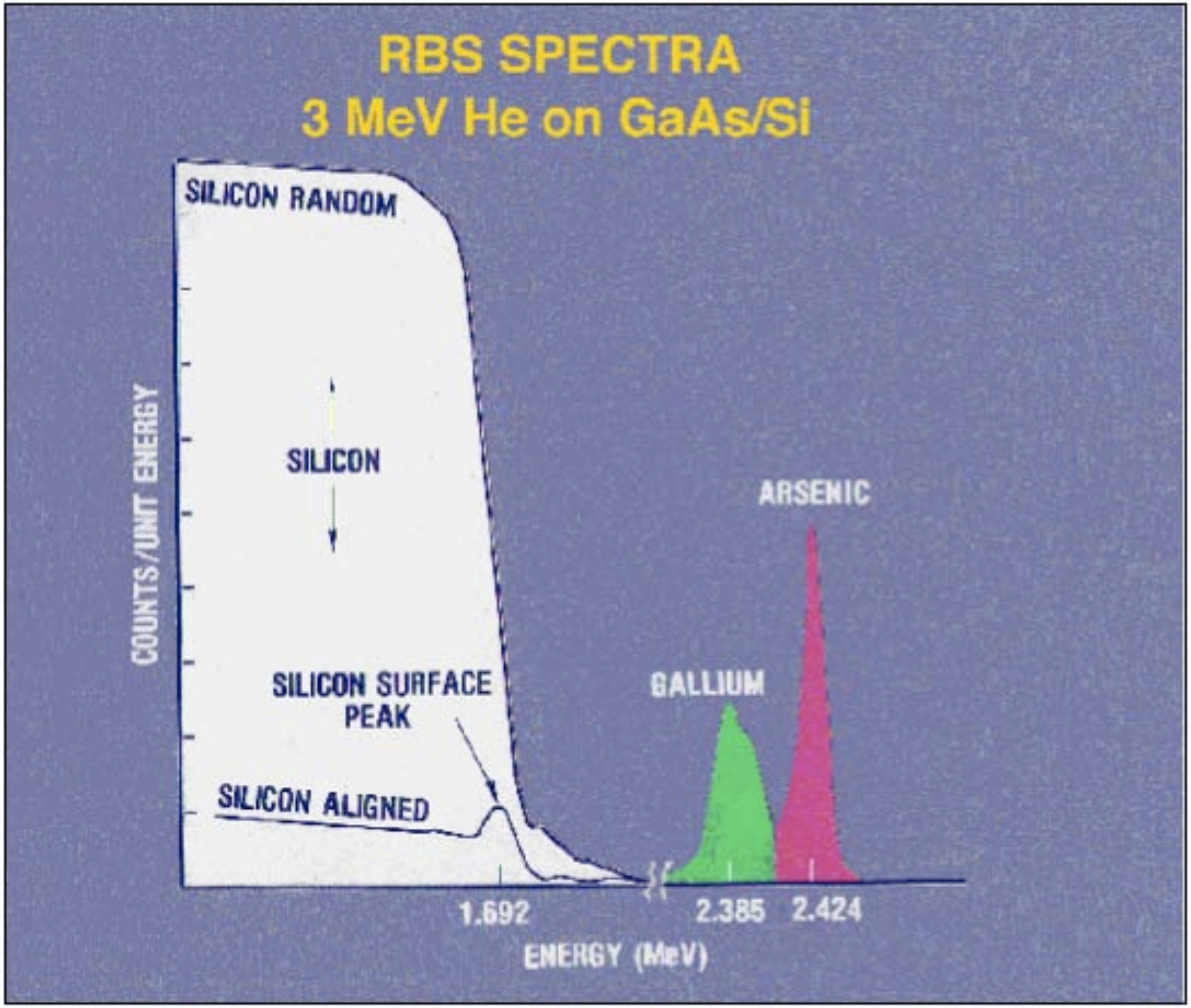
2.4 MeV
KCl·(KBr)x
4He+
Cl
K
Br
Backscattering counts (10^3)
Energy (MeV)
0
2
4
6
8
10
12
14
1.2
1.4
1.6
1.8
2.0


4 element film
substrate
E_0
Backscattering counts
K_4E_0
K_5E_0
K_3E_0
K_2E_0
K_1E_0
ΔE_1
ΔE_2
ΔE_3
Backscattered energy

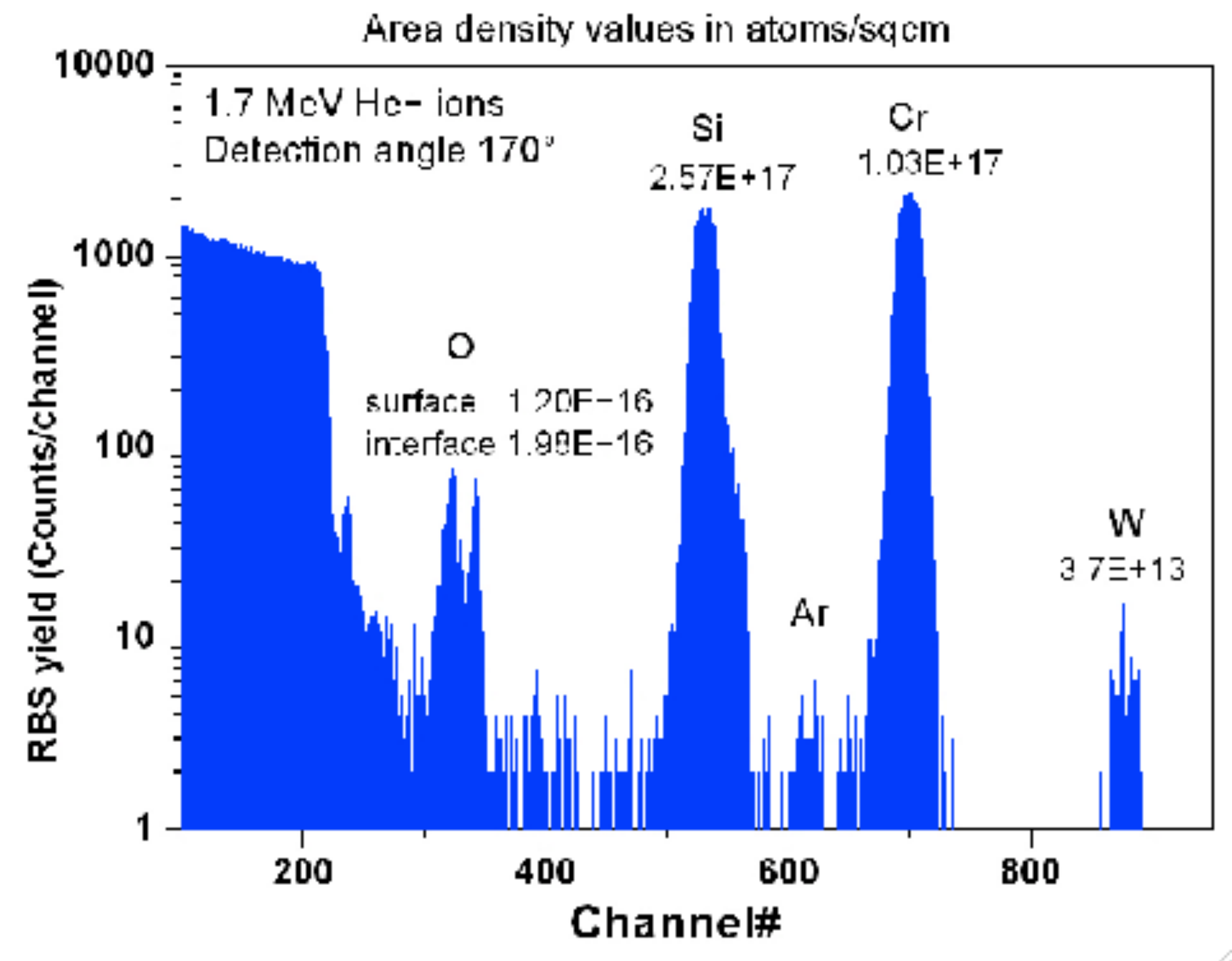
$M_4 < M_{SUB}$

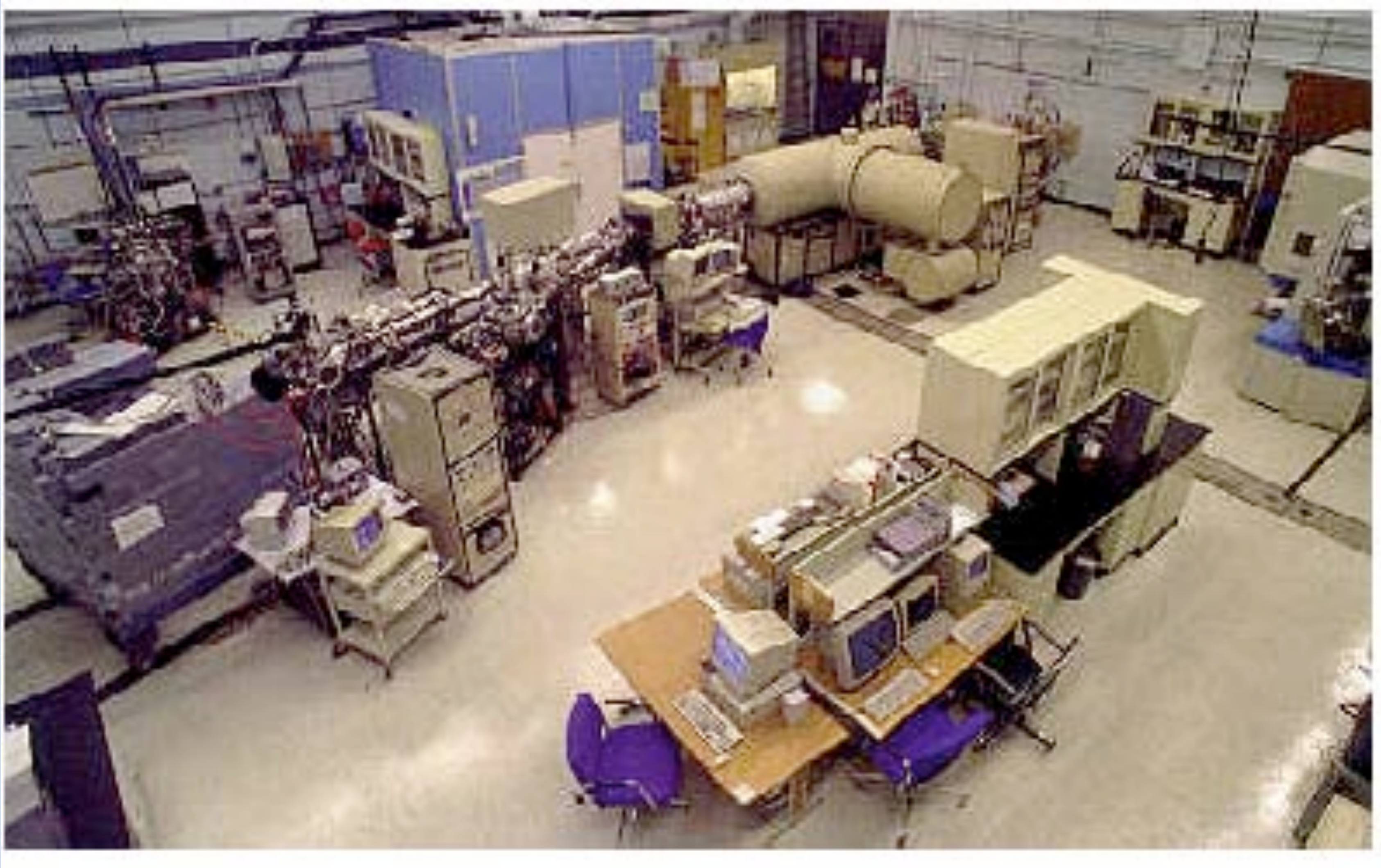


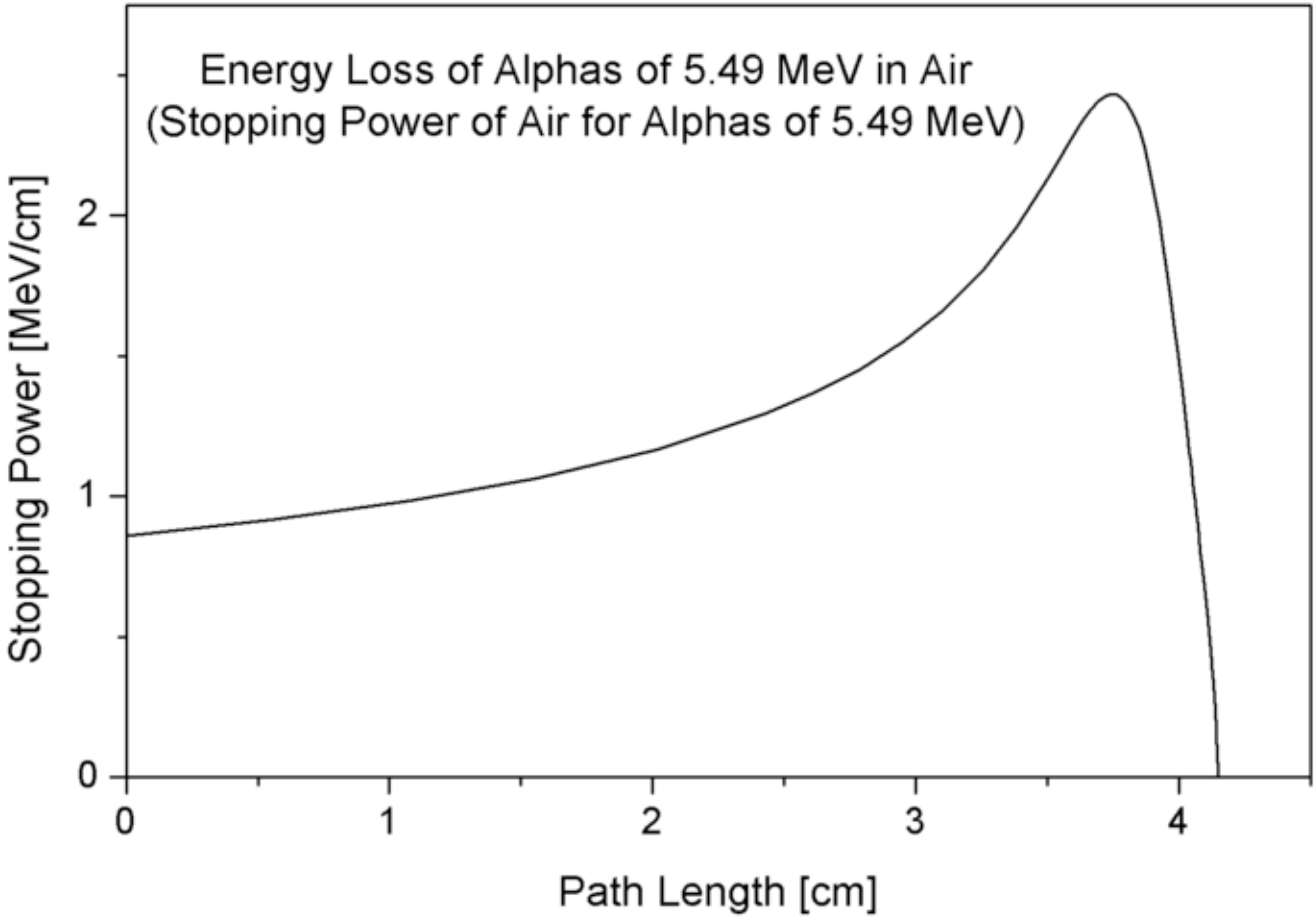
SOLID STATE
PARTICLE
DETECTOR
ION SOURCE
MAGNET
SILICON
SAMPLE
3 MeV He+
ACCELERATOR
SILICON
GALLIUM
ARSENIC



http://www.mrsec.harvard.edu/cams/RBS.html


Area density values in atoms/sqcm
1.7 MeV He+ ions
Detection angle 170°
Si
2.57E+17
Cr
1.03E+17
O
surface 1.20E-16
interface 1.98E-16
Ar
W
3.7E+13
10000
1000
100
10
1
200
400
600
800
RBS yield (Counts/channel)
Channel#





Energy Loss of Alphas of 5.49 MeV in Air
(Stopping Power of Air for Alphas of 5.49 MeV)
Stopping Power [MeV/cm]
Path Length [cm]
0
1
2
0
1
2
3
4

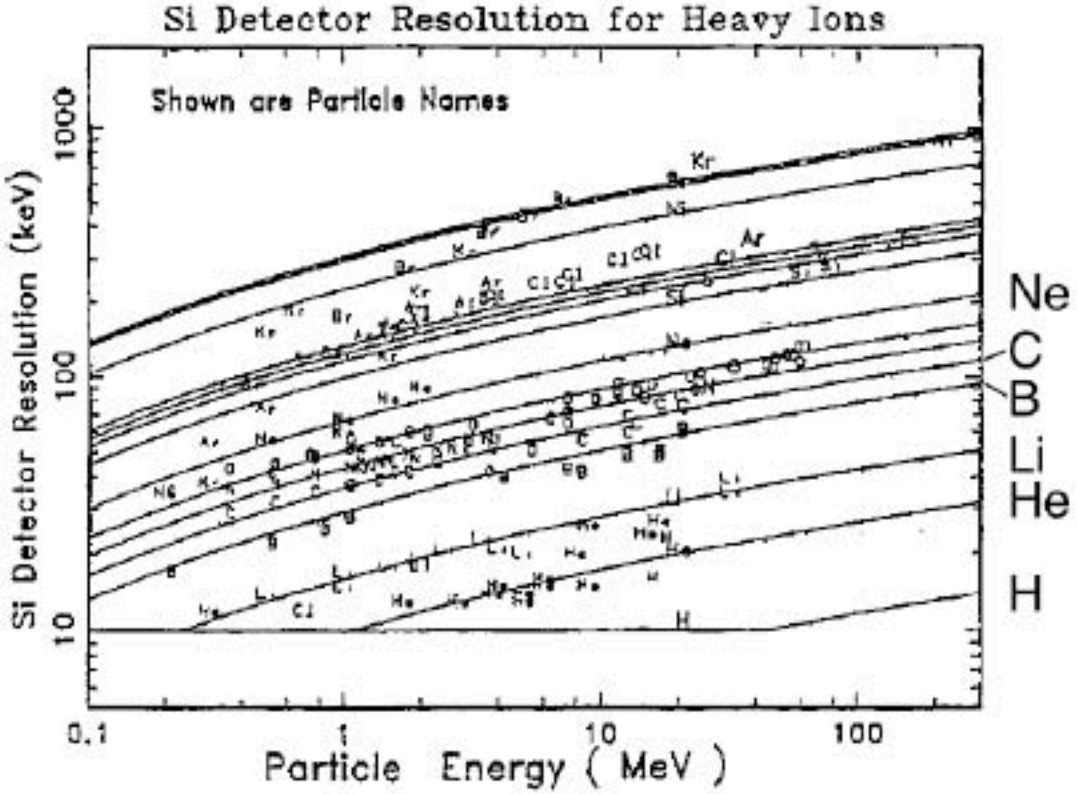
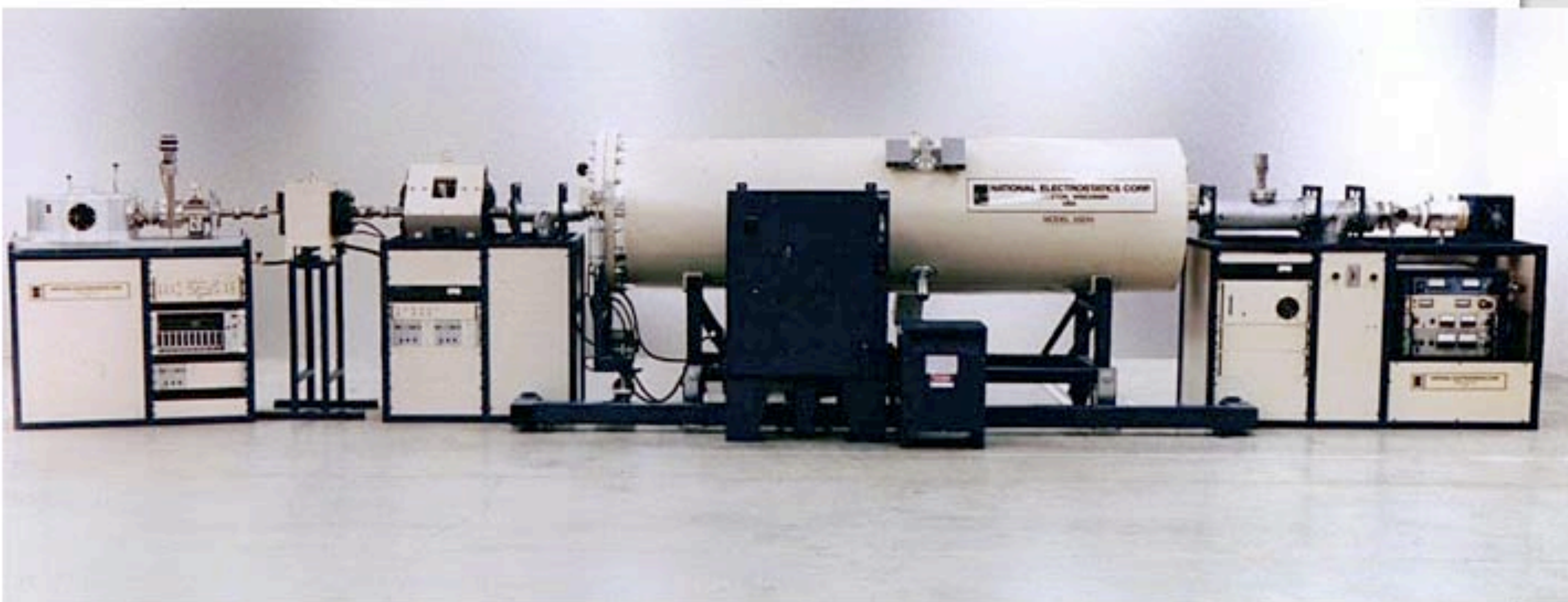


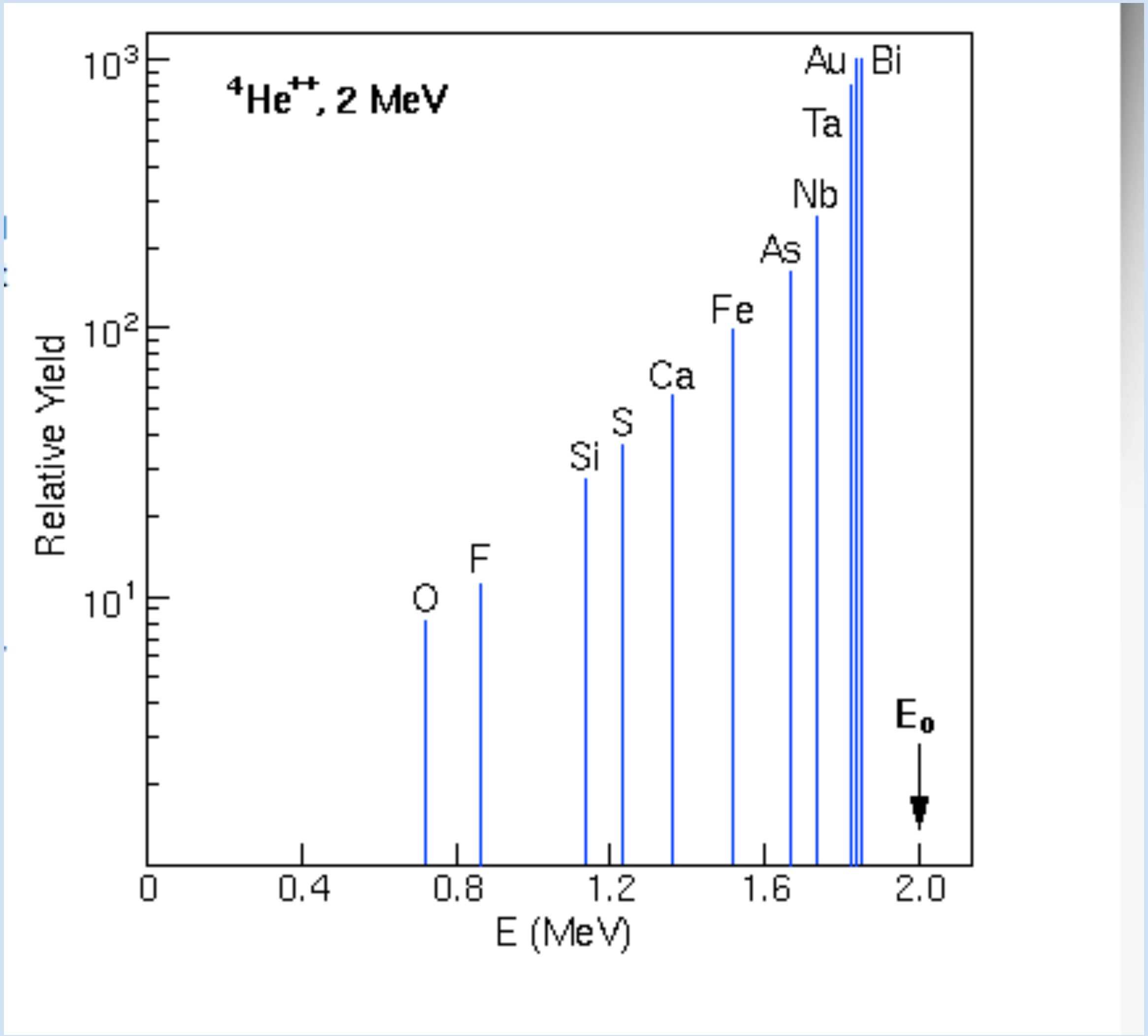
Figure 7: Silicon detector resolution for different ion species as a function of incident energy. From [22].

[22] J.F. Ziegler, Nucl. Instr. Meth. B136-138 (1998) 141.

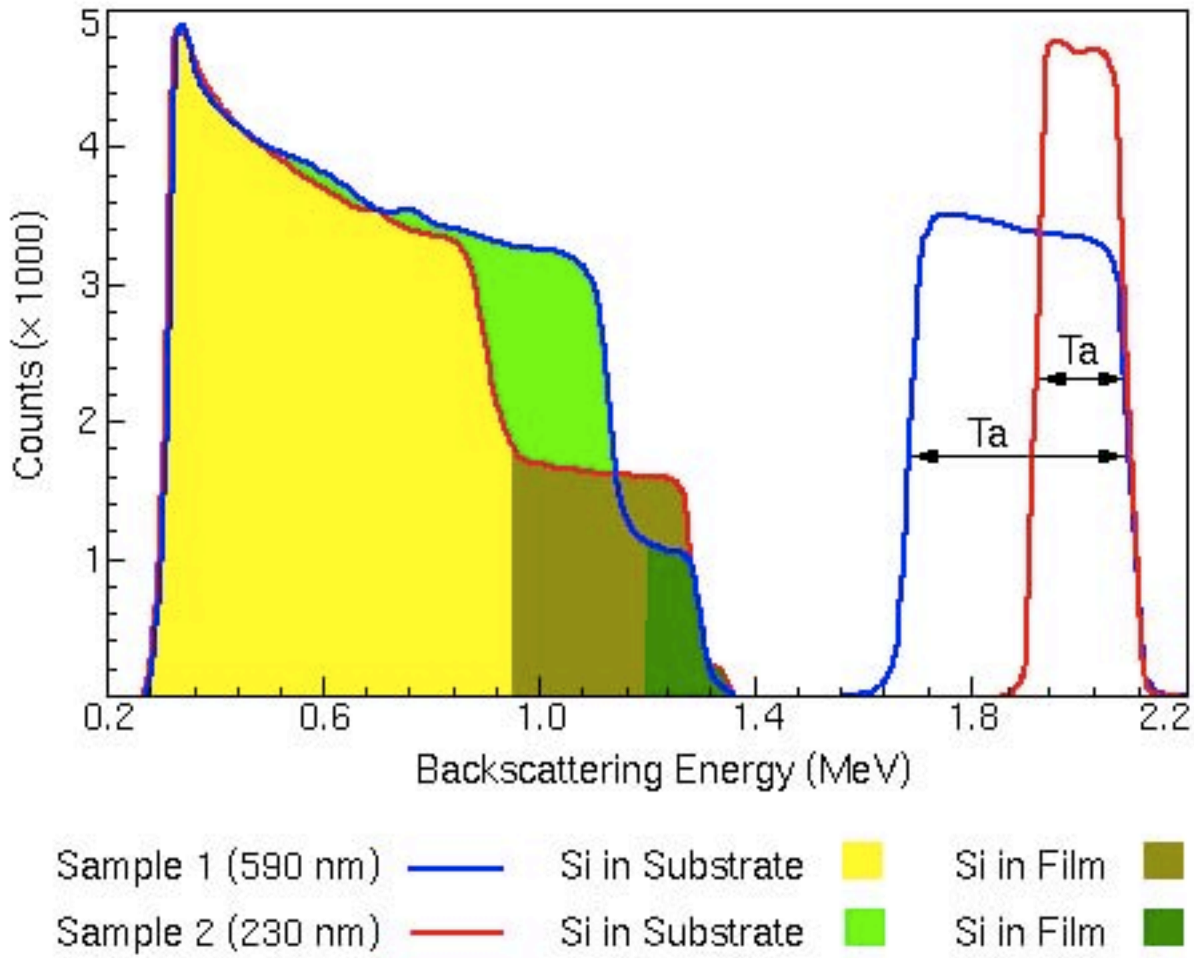
Ion Beam Analysis Facility (Materials Sciences Division/LBNL)

Location: building 53-022





$^4He^{++}$, 2 MeV
Relative Yield
10^3
10^2
10^1
O
F
Si
S
Ca
Fe
As
Nb
Ta
Au
Bi
E_o
0
0.4
0.8
1.2
1.6
2.0
E (MeV)



The height of a backscattering peak for a given layer is inversely proportional to the stopping cross section for that layer. The stopping cross section of TaSi is known to be only 1.37 times that of Si. This explains why the height of the peak corresponding to Si in the TaSi layer is less than one-half the height of the peak corresponding to Si in the substrate, even for a film with a Si:Ta ratio of 2:3.

Figure 12A

Three views of a model of a diamond lattice, as viewed from a: 1) random direction; 2) a planar direction [(111) plane] and 3) an axial direction [<110> direction].

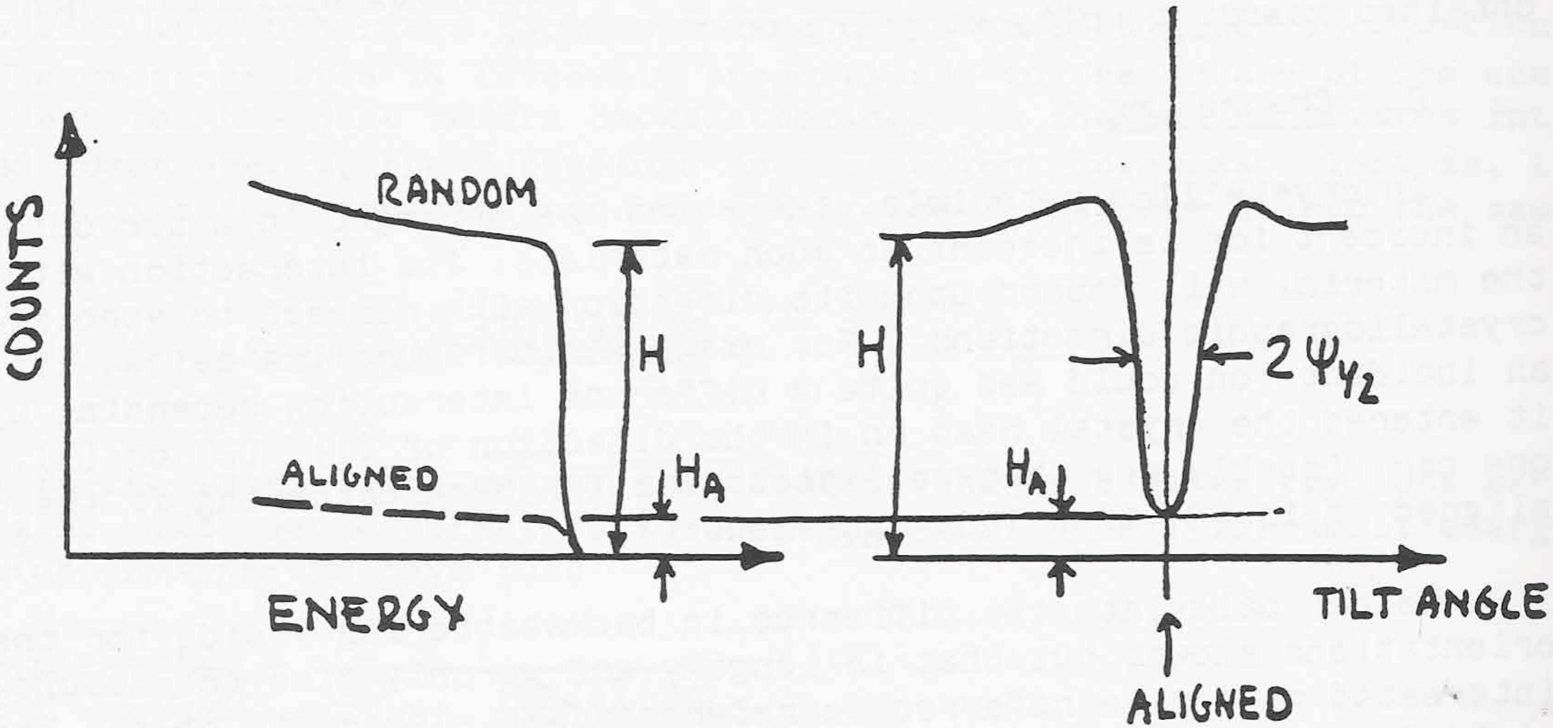

COUNTS
RANDOM
ALIGNED
H
H_A
ENERGY
H
H_A
$2\Psi_{1/2}$
TILT ANGLE
ALIGNED

FIGURE 12B.

Micro-Rutherford Backscattering Spectrometry/imaging

Kinomura, et.al. Nuc.Instr.Meth. In Phys. Res.B.33(1-4).1988.862

A. Kinomura et al. / Microprobe using focused 1.5 MeV

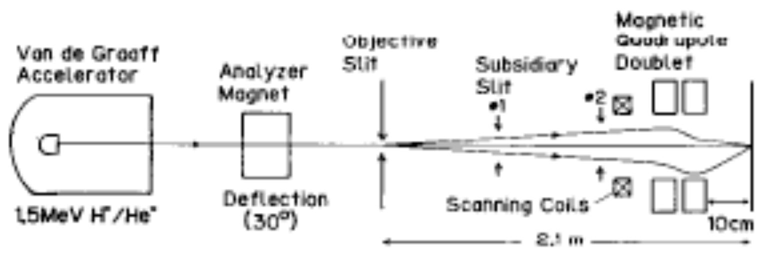


Fig. 1. Overview of the beam line.

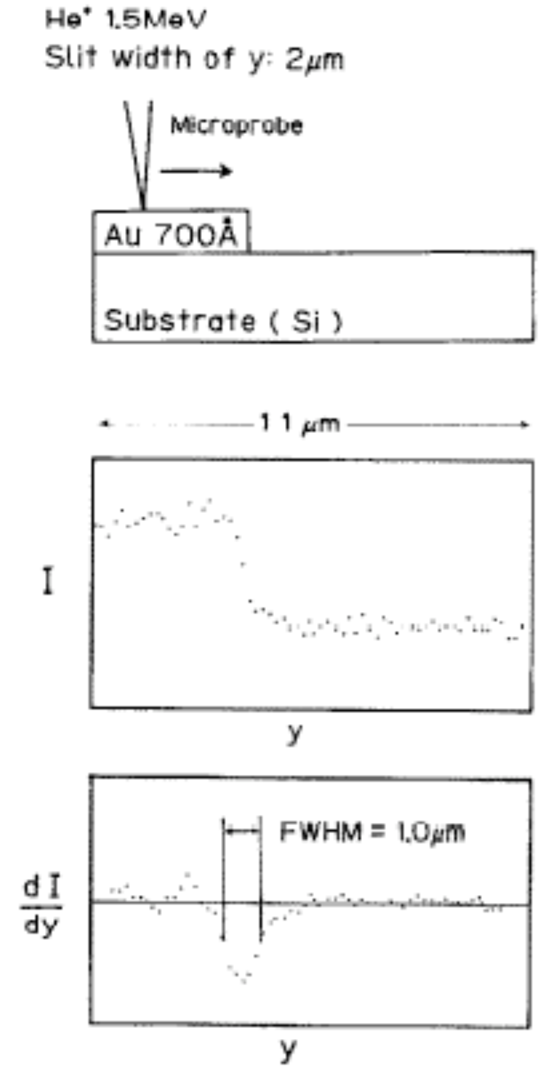


Fig. 2. Secondary electron intensity profile and its derivative obtained by scanning the microprobe across an edge of a gold pattern on a Si substrate: a minimum beam spot size of 1.0 μm (fwhm) for the vertical plane (y) is observed.

Micro-Rutherford Backscattering Spectrometry/imaging

Kinomura, et.al. Nuc.Instr.Meth. In Phys. Res.B.33(1-4).1988.862.

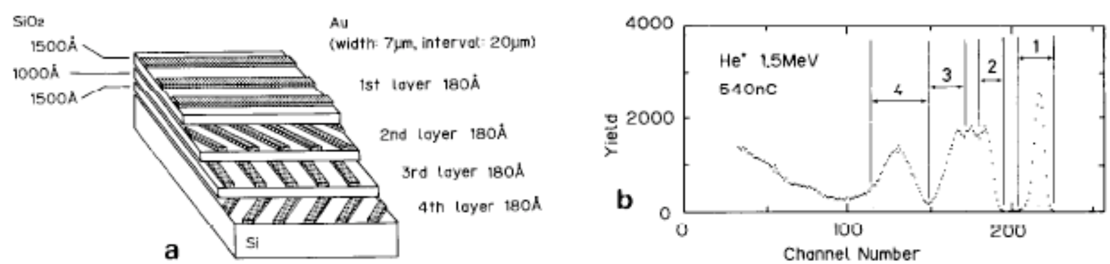


Fig. 3. Structure of the demonstrated sample: (a) Schematic diagram of the multilayered structure: four layers of Au gratings isolated with silicon dioxide layers are on a silicon substrate, which represent multilayered structures of wiring in integrated circuits. (b) RBS spectrum with a defocused beam: four peaks, corresponding to each layer, can be observed.

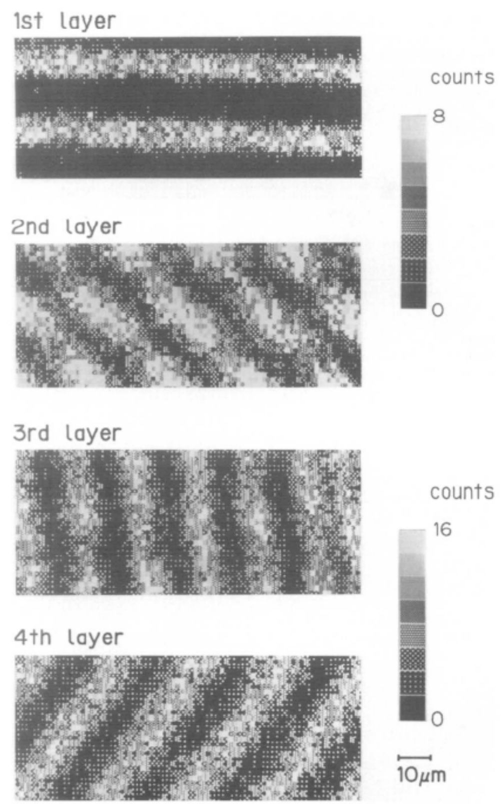


Fig. 5. RBS mapping images of the demonstrated sample obtained by adjusting the energy window of an SCA to each of the corresponding peaks observed in the RBS spectrum.

TABLE II

RBS Capabilities

mass resolution	1-10 amu
depth probed	< 1μ
depth resolution	100-200 Å
composition analysis	number of atoms per unit area, atom ratios [only atomic composition, no chemical information]
sensitivity	> 10^{10} atoms/cm^2 (heavy atoms in lighter atom matrix)
crystallinity	can get measure of crystalline order
lateral resolution	generally 1mm (except for preliminary investigations at 1-10μ)

References

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13. W.G. Morris, W. Katz, H. Bakru and A.W. Haberl, J. Vac. Sci. Tech. B.3(1), 391 (1985). "RBS Analysis With a 1μ Beam."

Rutherford Backscattering Spectrometry
Leonard J. Brillson
Published Online: 28 DEC 2012
DOI: 10.1002/9783527665709.ch11

Stopping Cross-Section, (1/N)dE/dx

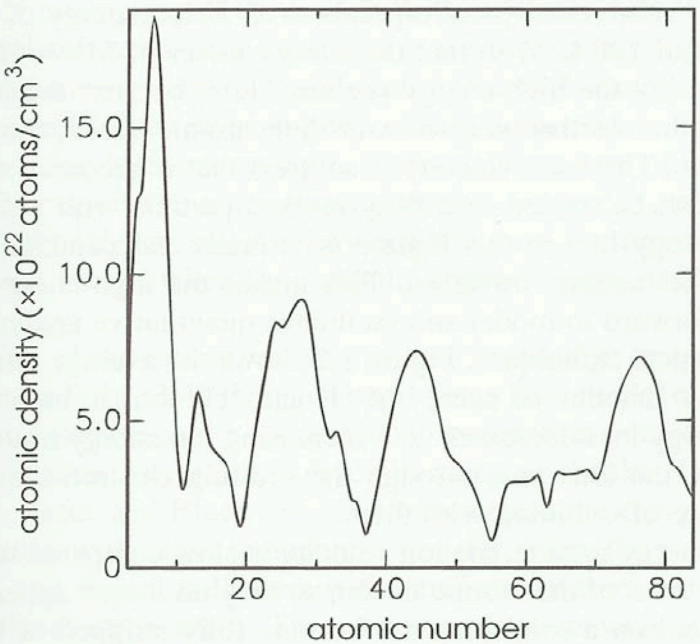

Figure 1.1. Variation in atomic density as a function of atomic number.

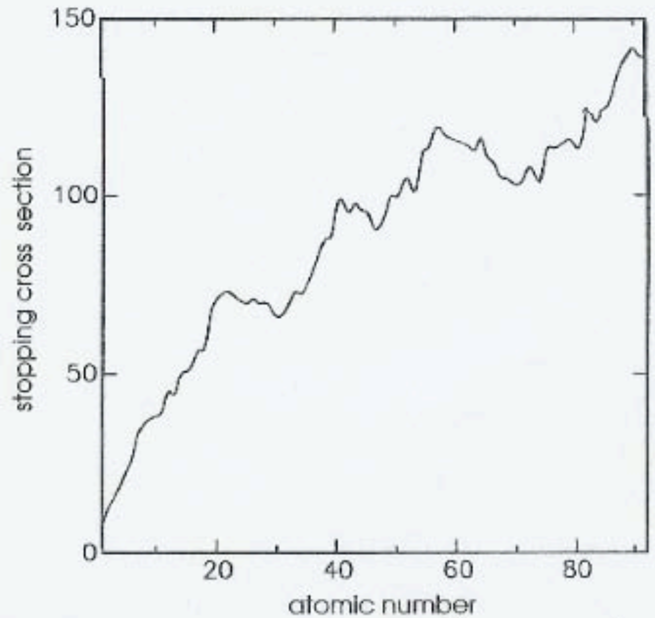

Figure 1.3. Stopping cross-section in units of eV/(10^{15} atoms · cm^{-2}) for 2 MeV ^{4}He ions as a function of atomic number.

From Breese, Jamieson and King. "Materials Analysis using a Nuclear Microprobe", (Wiley-Interscience, 1996)