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PUERTO RICO NUCLEAR CENTER

GAS STOPPING POWER MEASUREMENTS FOR ALPHA PARTICLES

Eddie Ortiz and Gilberto M. Arenas Rositlo

May 1973

(OPERATED BY UNIVERSITY OF PUERTO. RICO UNDER CONTRACT

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University of Puorto Rico

Mayagues Camps

GAS STOFPING POIGR YEASURENEVTS FOR ALPHA PARTICLES

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Gilberto Me Aranas Roatllo

A thesis subnitted in partial fultilinent

of the requirenents for the degree of

Master of Setence

(ttuclear Engineering)

May 1973

Metng Bigestar of Doparinant ~~ 7

?Hrecter, Gramate stiaies Date

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Amothod hes been doveloped to measure the etopping powers of fase for alpha particles using @ (Si) sentconductor detector nounted opposite a naturel An" aipha source in a gas chamber and a 102-chanenel data acquisition ayaten.

By varying the gas pressure and taking an energy loss neasure~ment at each pressure, the stopping powere and aolecular stepping cross sections vere calculated; also, range-energy relationships vere meas?ured sizultanecusly.

Trperinestal data are given for air, tlzy Opy COay NzOy Ay Key

Froon ty Gil, Onli,» Col, Ce and OH, for alpha particle in the

ange 063-5.0

eres eections ranges fron approxtzately 4-5 per cent at the highest.

energies to epproxinately 9-10 per cent at the lovest energie:

YoV alpha enerzy. The

tiated probablo error in the

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ACRIOMLEICDENT

It ds the author's wich to express his sincere eratitule to

?thooe sho helped tz to conplete this profects

To IR, BODIE ORTIZ, Sentor Selentist, thuclear Engineering

Division, Pusrte Aico uslear Center, for suszesting tho problea, for his dedicated guidance and competent muperviston of the work.

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Departzent, UPRARIM, for har constructive eritictan and for her
valushle advice.

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To the Colosbtan !ntotry of nes and Petrolevs-ICSTEE
Foundation for granting the finaneiel eostetance needed for comle-
ton of this projects

fo the personel of the Library ani Reproduction office of
the PRIC for their exexstery cooperation,

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pentcarzon

?To ny doar Esther
and Alejandro

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TASLE OF coursrrs

Theory

SEIT AID PROCEDURE

41 Detection Syetea Daseription

402 Brergy Lona Nessurszent

4-3 Cross Section Calculations

GuPIR V = RESULTS WD covetastoxs

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Sone chenical end physical properties of gases used

in this wr

Range-enerzy relationship of afr and hydrocarbon

Gases for ipsa particles

Yolecular stovning cross coctions of air and hydro

carbon pases for alpha particles

Coxparison of aolecular erves section remilts vith

data found in Literature

Instrmentetion Bquipaent settings for exparinents

Range and Shorcy Lose Sporizontal Data for 5.477

alpha particles in cir

Range and Shorcy Lose Expertzental Data for 5.477-leV

alpha particles in C:

Range and Eiersy Loss

alpha particles in 02%

prinontel Data for 5.477=i0v

Range and Shergy Loca Bperinental tata for 5.477-127

alpha particles in G33

Range end Snorcy Lose Fmperinental Data for 5.477-MeV

alpha perticies in Cai,

Eange end Scorey Lose Sxporinentel Data for 5-47

alpha particles in 2335

Range and Sherry Losa Export

?elpha particles in iin0

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Range and Rrergy Loss Sxperizontal Data for 5.47MaY

?alpha particles in A

Range and Brorcy Loss Sxperizental Date for 54477-MeV

alpha particles tn C2,

Range and therey Loss Brverinontal Data for 5.47MeY

?alpha particles tn ice

Range end Sherzy Loss Bwpertzental Date for S-L7I-UeY

alpha perticles in Freon-14

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Last oF FICuRES

Figure to.

eroizy 5. e59 of air at various goo proscires and

at 22,

47 Resainins cnorsy of 5.t7atior i247 atpha particles

after traversing a cartain poth Xytpy corresponding

to tio chasber gas procure for aif" ang hydrocarboa,

seo,

48 Ranaining enorey of 5.L7-Hev in" atphe particles

after travaroiag a cortain path Xptny corresponding

?to tho chasber gas pressure for Ay lity 02 and Coe

469 Resaining onensy of Sl7-tier 2:4! atona particles after

teavercins a certain path Xgen, cormasyoncing to the

ehasber gaa proacure for Kx)? ffo snd Freon te

4-10 Brorey lose of alpha particies tn atzy Oslig end Ogee

411 Rrarcy eas of alpha particles tn Gig, CR and C6

412 Berry Loss of alpha partictes tn A, Op and OOze

499 Bharzy 2ooo of atzhn particles An tzy Kezy 10 and

08 lhe

sth Ranzo curves for tho tn" athe partieloa (5447 tov anit

?weep:

otis cicrcy) and for alcla particles after

ng very thin Gx and TA foila tn air.

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3 ator

2 in latiane (GI)

Range curves for tho 1x1 esis purtdeles

Anitiel ?otic encray) end for elvis pert

?woaparsing vory thin Ou and Mi foils in Zt ticles (5.47 Mev

© pareicica after

respecting very thin Gu and M foils in Frozane (Osi)

na petioles (5.47 Nev

Range curves for the 1% tdeles (5047 Mov

Aitéel ?netic encr7) and for alte particles after

freapessing very tin Ouand Ti foils in Propylene

(3).

Rengoweuercy relatica of elow elpha particles in aie

and hydrocarbon gasca at standard conditions.

Range curves for As? ateha partictos (5447 Yev) ia

sovarel inargsnie g:ze3 (ay li2y 02, ?ig0)e

Range curves for An gizha partioles (5e47 Nev) tn

COgy eg and Zoom the

sections of air, Oni and

Yolecular etovning cress sections of Gi, O2ii, and

O3lig for alpha particies. *

Range-enercy relation of elow alpha particles in alr

at stancard conditions

a

ar

33

---Page Break---

Guprr 1

perromvorro

In recent yours there hes

8 considereble interest tn date

Telating to stopping pover of chargod partistes dn various saterials,

The aigniticancs of this paraneter aay bo rartioulary appreciated by

dleaentary-particls piystctote and nuclear plystetate in view of the

fact that the prectaioa vith witch nuclear reection cross sections can de mossured often depends on the

section of the tarvet =

curacy with ubich the stopping cross

rial 19 iow. Health physiotets neod stop»

Ping power ceaswezenis for radiation protection purposes because bio-

Jogical, chonical end physical effects produced by the charged partic

ele deposition in a ceiius like himan gott tissue (of eorposttion

10613, 0 124%, 1 4% and 073.

ty wotght) dopanda anong other

ainga, on the absorbed cose and oa the Linear nersy transfer of the

charged particle involved,

Mueray doposttion in tho material throw vtch the radiation

4a passing (stopping saterisl), 19 closely related to tho enorey lose

ty the ponetratiag radiation, The o

a7 lose of the penetrating

charged particle par wnith path lenzth in the stopping aterial te

called the stopping power of the saterial. Stopping power 49 depend=

et upon the various sechanicas tn utich radtation interact vith tne

Airidual atons and molecules ant ts an expression of the average cute

cone of a large number of Andtvidual tntoracctonas

---Page Break---

Stopping povar nessureaonts hava been carried out in various

solids, Liquid and gases as stopping aateriels, In this work, @

nothod 19 developed for measuring the stopping pover of several or-

aiconiuetor detector. By varying the gas pressure and take

ng en energy lose neasurenent at each presaure, stopping pover curves

and eolecular stopping cross sections ea « fiction of alpha enerey

have boca calculate?. Also, range curves and rango-energy relation=

ehip for 0.3 ~ 5.4 Me¥ alpha particles tn air and hydrocarbon gases vere developed similtanesusly. Rosults agreed within a 5 = 10% of eocuracy with respect to literature related datas

---Page Break---

as indicated by recent professional Literature, there 1s a re Rewod interost n the variation of stopping pouur of cases for heavy charged particles (vith « mass very much crater than the cass of the electron).

4 argo mount of experizentel work has bean done and thecret= teal expressions for stopping power have boon davaloved showing various degrees of accuracy.

R.B.J. PAIR (11) obtained Linear Energy Transfer (42/4) curves for 1 to 8 Nav alpha particles in hyérocerbon gases and hydrogens

E, ROTONDT (13) aeasured stopping powers for 0.1 to 5.3 alpha Particles in Ng, Og, Gi, end CO, by differentiating the range-enersy carves of those gases obtained ty neans of a varieblo-preseure gaa call tn vbtch Fo*Matpna particles lose part of thetr axersy and ware detect 04 by & soniconductor detector. ?These di/ax coasurezents have quoted accuracies of 8 per cant botveen 0.1 and 0.5 Mov, 5 per cont at 1 Mev and 3 per cont at higher ensretos, PDs BOURLAND, WoK. CHU and D. POWERS (4) measured stopping

ero

etions for elphe particles in a differentially pusped gasncall

systen froa 300 Key to 2

7 £m Hoy Higy Og Mlgy N0, CD, Czy Cty

Calley Callgs Callés O38 and (Gig).

GoD. KERR, Lat, RATER, Me UY

ROD and A,

1. WALTER (8) roported

experinantel data for air, tig, a, Kr, OW, for alphs particles

---Page Break---

4m the energy rangs X00 Kev ~ 5 lv. Moleculer cross sections of the

above cases vere calculated vithin an accuracy of approxtnately 4 per

ant of probable error at the hichost energies to approximately 12 per

cant at the lovest enersios.

PeJe WALIH (15) measured solecular stopping erose

Calg Cally and Cylig for 0.3 to 5 Yaw alpha particles vithin a 10 per

sstions for

cant of accuracy et the lovest cnsreies, using a variable-cressure

gas cell and a constant separation distance between the alpha source

and detector.

WP, JESSS end J. SADAUSSIS (7) detarained range-energy curves

4n the region 0 = 5 Nev for alzia particles vith a collinating absorp=

?ton call and ar ionization cheaber, Tle ionization change fron a

single alpha particle ine collected in the on chanbor and amplified

by means of the vibratinc-reed alectronoters

/A, BETIE (3) reported rango-enercy rolations for 0 to 6 Mev

eiphs particles and developed a theoretical treataent on stopping

power for heayy charged particles (Ses Section 3.3)+

---Page Break---

curr m1

THE DiTERACTT

OF ALPHA RADIATION (ITH MATTER

ALL radiation moasuresents depand on the interaction of the radiation with rater, The nature of these interactions therefore, forns the basis of a discussion of the coasurenenta theaselvos, and an outline of the principal interactions of charged particles 1ike alphas is developed in this section.

?The prinary nechanisa of energy loss tn penetrating charged particles 13 dus to Coulosb interactions betwwen atonie muclat and electrons with tho charged particles; to a lessor extent elastic and inelastic collisions with electrons and nuclei are also of stgnifi- emcees If the energy transferred to en electron is only enough to raise it to a higher leval tn the ston, the proce:

4s called axet~

tation; ¢ the electron 4s given enough energy to separate it com

pletely from the aton, the procass fs called ionization. the two

process

are closely ascociated and together they constitute "energy

oso ty collision". At energies several tines the rest enerey of

?the uoving charged particle excitation and tonization account for the

eajor part of the exercy loss in all saterials. Soue of the electrons

ejected tn sontzation process

Ihave ancugh energies to produce fu

?ther donization thacselves; such electrons are called 5 -Rayas

---Page Break---

9f other shenosens occur vion alpha particles traverse

natter. Interactions with the coulosb fields of atoas, and particular

Ay of atonic nuclet, result in chance in the direction of motion of

?the heavy particle (tho tora Theavy particle" shall afterhere refer to

4 particle of a aacs greater then that of the electron). Inelastic

collisions with electrons are by far the most dnportant processes by

Which @ penetrating !

avy charged particle loses ite kinetic easrsy

hon the velocity of the particle, v, 4s auch greater than Yoy the ve:

locity of the electron (in hydrogen vo = 2-183 x 10° ea/sec, while for

4@5e477=HOV alpha, v= 1.623 x 10 ca/soe). If kinetic enercy is

conserved, the process is celled alastic scattering} such scattering

4s of ainor inportance for heavy particles tut of great inportance for electrons

Scattering throug a large angle oataile a largs accelera~

Hon of the charged particle, This in tum say result in the eaisston

of a quantus of clectronagnetic radiation, known aa broasstrahling, which

Decouss inportant wien electrons aro involved.

31 Gollsston Loss and Stoning Power. According to the classical

Point of view, a soving charsed particle loses energy to an electron

by Aaperting to it an ispuise proportional to the atrensth of the

coulead force and to tho tine during witeh this force actos Since

the nonontun acquired by the electron 42 proportional to the tine

uring which the interaction takes place, St 18 inversely propor

?tonal to the velocity v, of the soving particle. The energy acquired

---Page Break---

by the alectron, and hence the anorgy Lost by the particle, mst tharetore, be proportional to 1/, ?This on the classical picture

elie anergy 1oea) show

te Proportsons to the electron denstty in the codtus and inversely

?the ensrey loss per mit path Length (sp

Froportionat to the square of the velocity of the particle, hen

the penotrating particle 4s noving 20 slowly (v <vg) thet 4o, aver

fg0 ast cherze approaches coma, the average enorcy lose per watt

Aength of path to electrons decreesos to zero, proporticnal to the

Velocity of the penetrating particle ifte the averaco energy lose

ue to olastic nuclear callistons ts inereasing proportional to 1/2.

Tho charged particles aoving throwch matter transfer thetr

snerey preferentially to tices alectrons that are closer to their

tracts. The farther an electron

fron the track of the alpha par

tele, the sneller tho imulce it can receive, and hence tio onaller

?the energy that can be transferred to it. If that energy 4 just less

?Shan the acount required to raise a K-electron to a highor energy low

ely no energy will bo lost to a Keloctron at that distance. Sone stint farther any losses to Laloctron wlll becone tnposaible, and 20

ote The nore tightly bound the atonie electrons (Ju:

the atoste mumter), the shorter vill be

the higher

10 "cutnoff" distances end

the ecaller tho rate of enorgy loss. Concoquently the rate of energy

Joss 1s expected to show sone dependence on atonic nunber, being svaller

at high atoste mabers.

---Page Break---

At valoctttes approaching the velocity of Light, the 1/e2 dex

Pandance ie modified ty a relativictte of

ects The relativistic con

traction of the electric field of the coving alpha particle makes

posathle mezzy Lose:

Fate of energy Loos inom

t creator distances, and in consequence the

os slowly at very high energies.

The stopping power to defined us tine anercy lost by the heavy

charged particle (alpie, in ou cass) por unit path An the stopping

subotance and is given ty the expression:

8(B) =~ (a5/ax)

where E is the classical Kinetic mercy of the particles

Stopping pover varies with the energy of the particle end the

Fango of tho particle can be calculated byt

Spe | os

Be f f sa) ?2 wdifax (G2)

where B is the rango and Zp is tho initial Kinetic eneray of the par

tele,

Stopping pover can be detornined o:pertaontally ty measuring

the enerey of the particles, which have gone throwh a certain thick

?Reso oa substance, If the rango ie Imcim ag a Amction of Z, the

stopping power can be obtained frost

a 4

= 6.3)

a s(e)

---Page Break---

3+2 Stomrin: Cro-3 Sections Tho aolecwer stopping cross section «

4s defined as the enercy loss

solecule per unit ares normal to the

path of the particle, tees:

4)

there 62/3x 49 the energy loss per unit path learth or Linear stopping power and n is the mnber of nolecules per uit volime. The stopping erosa section is used since it 13 @ quantity independent of g20 pressure or tezperatice,

Xf the dlstance traveled by the particle is held constant and the mmter of atens along &

Path of tho particle becomes the variae ?Ble cn which the cnergy loss deponds, the atove equation should be written in this forat

e = -1428 2 1 Ge-8) (6.5)

Tn both equations, By roprosenta the enercy of the incident particle on the auterial cud £2 represents the reduaed energy after penetrating Rox oF dan solocules par unit ares normal to the path of tho partie ele.

4a oxprosion cen be derived for in dn terns of the variables Toamured fn this investization by the use of tho Lave of Avogadro, Boyle and Charles with the folloving relationship:

ok

a= oh (3.8)

---Page Break---

here p is the density of 2

pping uateriel, W te the atonte

weight and A ts the Avogadro?s number, Also, ve ean deduct fros

the atonte theory:

Rg = mz 0.7)

share ng 40 the electronic density and Z 10 the atonte number of the

substance. Froa Bq. (3-2) ve follove

Row £ (1/2) = f (1/n9) (3.8)

But ng 1s directly proportional to the density of the materials, 20

?the rengo R vill be proportional 1). Fron the general law of gases,

PY = Hag G09)

whore M ie the molecular naos, Ry {0 the gas constant, P 4 the pres

sure and T Le the tenperature in the valune V. Rearranging the last expression ve gett

*

Fae oe (10)

Fron Eq, (3-10) vo can see that (P/T) te directly proportional to n OF ng, oF inversely proportional to the range R. Written in the other way,

Fooonet G1)

---Page Break---

"

Bearranging the last expression,

13)

stiero the wubscripte ?oY seans standard conditions and

B= oof 6.13)

Inserting Bae (3.12) into 2g. (345) the acleculer stopping eroea wec-

?ton can bo calculated from the collected exparinental data using the

vegultent formula:

ee 22 RRAB (3.14)

th? ya

Nhere the ooan residual exergy of the alpha particle after traven-

fing the distance d with a pressure Py in the chazber 4e Ey and the

?mean residual enorzy Ea 1s the decreased cnergy of the particle after

reversing tho chasbar at the pressure Py (AP = Py = Py } Bp By)e

343 Eatho?s Theory. (See reference 14) Bothe?s theoretical treataent

of the mercy lose 42 tagod on Born?e approxization, applied to the

edllision between the heavy (alpha) particle and ?the atomic electrons

An this thoory the differential cross section for the process in vbich

?the alpha particle transfers a given azomt of energy to the atonio

Mlectrons is givon by the square of the natrix ele:

1t of the coulosb

Antaraction botvsen appropiate initial and finel states, Plane waves are used for tho inve Aumetions of the

ident end acattered alpha

Particle, the kinotie enorpies being E ani E' (S-E), respectively.

---Page Break---

2

The condition of the aton ts described dnttiai?y by the iperturbed

atomic wave finct:

for the ground state and finally by the wave

fmmetion for ono of the excited sta!

seltiplying the ress sec

tion for @ givon enerzy lose by the =

rey lost and owning over all

Possibilities gives the final axcregsisn fer the average energy lost

per contineter of path.

Veo of the Bom approxination requires that the anplituie of

the vave scattered by ths field of the atoate electson shall be

small coxpered to the axplitude of the undisturbed incident wave. As

At 4s well inom tho ertterion for this is that:

wo, (3.15)

tr

where zo and v are tho charge and velocity of the prinary particle,

Fespectively and % 4e the Planck

constant. Tate condition te well

satisfied for large velocities and suall charge of the incident pam

Hele. Equation (3415) 1s also, essantially the condition for the

Particle to have its 2ull changes when £q. (3-15) ds not fuletited,

?the particle toring to capture electrons. The ealewlation of the

stopping power {9 nada mich stapler 4¢ the velocity of the incident

Particle not only fulfils Bq. (2-15) but 4s dn addttton, Large

compared vith tho valccities of the electrons within the atoaa, 4.

an

Be Bay (3.16)

where E ts the easy

the Anofdent particle, 243 the donfeation,

---Page Break---

B

potential of the elestrona, and Mand s the aasceo of the tnetdent

partlete and the electron, respectively.

Tnder those conditions and tor xomralativistic velocttien the

path or "topping power der

2

-a- ate os G17)

B= ti EE) (.170)

average enorzy loss par centizeter

vith

Hare ¥ 4s the velocity and 20 the charge of the incident particle,

the munter of atoas por cubic centtaater of the material, the micleer

charge, I the average excitation potenticl of the atoa, and the dizen

stone:

Jogarithnic term B the "stopping number",

For relativistic velocitios of the incident particle 4t 13

show by Bethe that:

Bow 2 (tog BE tog (4-22) = 2 G18)

whore $= v/s and c 40 the valocity of Light. Although Equations

(3617) end (3.18) vare derived for otmple "hydrogenlike" atons, it

ean be apaliod to other absorbers by adjusting I. The value of Tis

dest dotamined from know ranzewnery data, from vich 4 4s found

?that I (given in electron volts) io related to 2 ty:

Ios ns for Z <0

19)

I+ sez for 2 > 30

---Page Break---

%

?Fron Equstion (3.17) the following relationships are evident:

(a) Stopping power 1s proportional to electron density of the

nedium (WZ),

(b) Stovotng power 4a proportional to the equare of the charge

of the incident particles

Gey the stopping powar for prow

tons 4s 1/4 that for alpha particles having the eazs valo=

city. (Velocities are the sano for protons having 1/4, the

energy of alpha particles),

(c) Stopping povur increases vith decreasing particle valoc!ty.

---Page Break---

A Mock dingras of the detection

eysten used tn this project 19 given tn ficwe fete A nochanieal

om PND vm wed to lovar the pr

ewe dn the chatbers The prose

sae within the center as sousured wth @ cereury canocoter, Leake

#20 of stoppin; cas into the chester vas controled ty a manifolds

49 alpha source scimce uae placed opzoeite a soateontuetor detector

in the gas chante:

?The munber of colecules along the path of the

Particle vaich provide the anergy loca nechanisn (couloubie inter.

eetions with the clestrons) we varied by chansing the gas presmure

tn the che:

Tho reckdval energy of tho alphe particles after

?traversing the seraration distance botimen the source and dotestor,

st a imow cas texperature and prosmure, 4s doterainod fea the alba

spectra obtained fron an enalyzer syste: consisting of @ aecieconduoe

tor (St) detector, « bas power supply, a mileer, a preaaplifior, ea

explifior and a multichannel pulse helght analyzer,

4 conara

?sure of tho laboratory soteup de shown in figure

42 end a ors

?bor close-up ean be eon on Sure 43. ?The alpha

Particle source wed dn this exporizont was a calibrated 0.1 aieroca

Ho s5?T soureo, wc had a negligtite ealfestaorption and a mint sm bactocattorin:, Tats alka source docays by enitting a 5.477-Ier

J vas assumed

a we SALSBAIOe (13.6

---Page Break---

6

fem] [oy

-

vecoum

pomp preamp

detector [omelitier

Ly collimators |

Tt?adjustms | height

cylinder | red

chamb

Figure Yo 441: Schenatic dingran of the experizental arrangenents

---Page Break---

Figure 4.2 1 Experizentel eet up for

stopping power and range weesuresents.

---Page Break---

Figure 4.3 +

of the experinental

set ups

---Page Break---

9

percent) oni 5.37AUioy (1-4 percent). The detector used was of the

cnsitive aren of 1 cx? and a

2 lever of approximately 200

angsteocs (© nich ins die alsost eatizciy vo the gold electrode on

eilican murfecosbarrier type wi

typical insansitive tusiness or

the surface. A crash of saarsy Joes 41 tho doad layer vay alpha pam

9 linear stopping power of gold

for alpha particies() auttinlio? by the dead layer thictness. The

eph showed that = 5.5, 140 end 042 esha particle dneident on the tele enerzy vas constructed using

detector suffered an enargy loss in penctating the dead layer of 10,

15 and @ Kev, respect

aly, Thus, the detector vas essentially free

of complicating Nwindov" effects. Tt has been show) that the res

ponse of solid atate detectors are Linear for alpha particles over

?the energy range of our experizent.

Tho source and the detector vere nounted in Line within the

chaster end tho separation distance could be varied by means of an

adjustable rod upoa hich the eource is aounted. Source and detector

are shown in figure 44. Also, an aluaimun colLinators were placed

over the alpia acurco and the detector 4a order to got a collinated

dean of alrha particl

4-2 Bronce Loss oagimenent= The calibration factor tn Kor/channel

for the energy analyzing cystes vas obtcined by means of a puleer

observing first the sero exergy position end then by observing the lo

cation of the 5.477a!ie7 alzha peck ville the chanber vas under vac.

The eclitrets

save and factor obtatned 4e show in figure 4e5e

The calttration factor (7.77 Sev/chental) wma also noagured after

---Page Break---

oo

Figure 4.4 +

Vacmes char

---Page Break---

srommye/aey 114 gon

Pourqo zoyo8y woRRMMTTH *woRkTwY ABroue ToD Feol ¥ PUY sOETR ABzotO WO

30 suves 4q pourrge ?uesete SupisveN amod Supddoye or OF eam woRIVIATTED # Sry emIts

¥aEWAN T2NNVHD

oo8 009 ?oor oz

AOW ?AOWIN3 asInd

---Page Break---

08a ceascrenents, Yo aigulficant drifts vere

ebsorved tn the caro energy pecition. The teapereture of the 2ab-oratory vos saintained within 1°F of a xean tesperature (75°F) 80 ?hat Lt wna possible vo avamge several sots of anergy lose mans wrecents on occh gas.

Using the 5.477 Moy te erine particle and a fixod source detector aistonce, enorzy opectra at cover different presnres

were taken for each of the gases considered, Information on the

gases used on the axrerinents in given in Tahlo 4.1, ond an example of several cxarsy spectra of alpha particles after traversing 5.4

cas of cir at various ges preagures and et 2,°C 4s shown on figure

4.6. Multiplying tho calibration factor (Kov/channel) by the channel.

munber of tho alpha pon, wo found tho avarecod peak enersy of the

alpha particlos reaching the detector after traversing through tho

stopping gas at e given chanbor pressure. Using a aimple relation

abip fron Ba. (3-12) we got an expression for calculating the equive

Metance travarsed by the algha particle at chanber conditions. In

other vordo,

Bo. Poh

Xotp Fe = ae FS 1)

shore tho cubsoripts "0" and ch? nean etandard and chamber condi=

tions respectively, and 4 4s the copazation distance between the

alps source and dotcctor within tho chasher. The Last oxpreasion

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TABLE 41

?SOME CICRILGAL AND PHYSICAL PROPERTIES OF GASES USED TY THIS WORK

cas. smucrre? YOUSOULAR WEIGHT? STANDARD DBISETT

Mt (ga/sole) 0 (e/ex)

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a 39.95 1.789

Me 23.01 1.251

& 83480 36736

02 316998 16429

2 geceg sl) yoy 197

m0 aMaategs

Freon 1 170.92 7.036

5

i, neG-a 16.04 o.717

HH

ue

coy Be 28.05 1.252

BE

2% BGpe 30.07 4.342

¥

EEE

eat 1878

¥

Rg

e383 Beta 4009 1.967

eae

4s Given by Pauling (92), unless otherwise specified.

21 ahvon By toast (15)," ao)

ja): Given by Orvillo-Thonas|

(b): Given by Bont (2).

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*ogte 48 pue comnsoext 928 emoTsaA 90 To

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WaGWAN 13NNVHD

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WIL 2AI1 "235 OOP NI 13NNVH2 Yad SINNOD

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nay be rearranged ag St follows t

«4.23 (hota)

Tetp = 4 Fo

somining that the tesperature quotient (To/Teh) 4s approxtnataly equal to wntty.

Brperizental energy and chaster prossure data for each of the 0s0n mentioned in Teblo 4.1 wore taken by varying the gas preseures on the chasbor at intervals of 1 to 10 canticotare of mercury and the results wore plotted in figures 4.7, 4.8 and 4.9. By atfteren tating graphically these curves, the stopping power perasotera vore caloulated toking ox = 1m, and en average valuo for the corres

ponding enercy In other words, Af AE = Ey = Eyy Egyor = (B1 + £2)/2.

Finally, the stopping pover (~ d8/éx) vas plotted againat Eaves for

each ges. The results are given in figures 410 to 4e13e

Ranges of alpina particles with enerzies between 2.60 and 5.47

Nov ware detarained simultaneously vith tae stopping pow neasuro-

nents by counting the number of alpha particles of a cortain enorziea

reaching tho detector in a fixed period of tino at a given gas prow

sures In onder to decroaso eipha energies, very thin natal foils

(out 0.00004" and 0.000125 Tis 0.00015" and 0.0002" thick) were

placed over the 5./7aev alpha source and tho enorgy peaks coming fron

the decreased energy particles shom acceptable broadening averaging

FeOhy heSkhy 23, 4002, 34535 3427 and 2.60 How obtained using Andi

?viduel and conbined notal foils. Ax and hydrocarbon gases wore

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B

chosen for this part of the axperinents end tho resulte aro tabulated

98 Table 4.2 and plotted on Figures 4.14 to 020. ditional range

date for other gases auch as O25 M2, 002, A2, Erp, MgO and Freonet4

48 prosented on Figures 4.21 and 4.22 for 5.47-Viev alpha particles

Range curves were calculated by norualizing the total counts using

the ratio of total comts and naximn total counts recorded by the

scalar for the sane period of tine. Table A.1 (ese Apendix) ip a ree

cord of the

tings of the inatmicents used on the axperizental

Beasuresants.

4-3 Groas Section Galevtations.

and hydrocarbon gases (Ci, Cali, CaM, O3H3, C3lis) vere calculated

by weans of Zquation (3.14) and tho following constant valuest

Avogadro's mnber (A): 6.024 x 10 aolecules/sran mole

Standard Texporature (7): 273°K

Molecular cross sections for air

Standard Prossure (P,): 760 ma of nereury.

Source to detector distance (a): 5.4 cae.

Molecular veicht and standard density values for each gas to

?be Anserted on Byustion (3.14) are given in Table Jet. Croas Sections

for air, nothsno, ethano, propane, othylene and propylene for 0.3 =

5.0 Mov alplia particles are tabulated on Table 4.3, and curves o:

Bolocular cross sections (10"Mev/antecule/ex2 versus alsha energy

(ex) were drown tn Figures 4.23 and 4e2he

---Page Break---

REMEDY ROLAT

PARTICLE

BERT,

Mev

5047

5.04

48h,

423

4.06

3653

3638

227

2.60

1643

3.89

3653

3432

2B

2.63

2.10

141

TABLE 4.2

a

427

3674

3652

242

1.92

178

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SIP OF AIR AID HYDROGAR

FOR ALPHA FARTTOLEs®

Rue, cus

a, alg

2.96

2.38 -

213 2.00

1631642.

1531435

W19 1.06

0.69 O68.

* These values are plotted in Figure 4.2s

GASES

ose

2.05

157

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38

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RANGE, ems

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ALPHA ENERGY, MeV

Figure 4.09 + Ransom:

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CoH,

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TABLE 4.3

MOLBOULAR STOPPING CROSS SDOTIONS OF AR #11D HYDROCARBOW GASES

FOR ALPHA PARTICLSS*

anh, tay tae OCOe

0.3 - - 13.5 196 235 26.0

Oh - - 16.0 213 28.5 27.0

05 55 - 1762 225 21 215

ob aks mse

er ee

12 9 1S 265 16.0 15S 22.6

166 5S 663 1064 1267 We Wd

2.0 8.0 55 cy) 10.6 1267 1406

28 55 AS 7600 8.0 10-1 Wed

32 ?7 rd 72 93 1065

---Page Break---

CONT. TABLE 443

nem

oo,

vat

at

36

ae

40

42

bs

b6

be

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* Those values are plotted in Figures 4.23 and 4e2be

am

be

403

bet

39

28

Be

37

366

35

MOLECULAR, STOPPING CROSS SECTION

(10-4 ev/aolecule/en*)

my

309

308

36

35

33

32

3A

3.0

29

Cai,

6.2

6.0

58

566

Soh,

50

5.0

49

he

ale

69

67

665

63,

Gt

569

BT

56

55

ORG

89

8.6

83

8.0

18

16

Th

13

ms

Cig

10.0

7

Qh

9.0

87

8.6

8.4,

8.0

---Page Break---

a4

8

MOLECULAR CROSS SECTION, 10 ?ev/molecul

3

1 2 3 4 5

ALPHA ENERGY, MeV

Figure 4.23 : Yolecwlar stopping cross sections of air, Opis and

Gilg for elpha particle:

---Page Break---

ar

3

8

8

MOLECULAR CROSS SECTION, 16!ev/molecule/em?

3

ALPHA ENERGY, Mev

Figure 4.24 : Molecular stopping eross sections of Gly, Cyi{, and

O38 for alpha particles. ?ar Cal,

---Page Break---

CUPTER

RESULTS 21D cotictustons

?The accuracy of tho stopping power and olscular ross sections

saleulated in this investigation depends on the folloving quantities:

?Je~ Gua Frossure: The difference hotwen the two colums of the

Rereury Banosoter could be read to an accuracy of + 0,5 mn of nereury.

?Thus, the error in P ranged fron 0.4 porcent for the largest preseure

intervals, to 6 percent for the sxallest pressure intervals. The

pressure intervals ranged fron 113 a2 of aercury at the highest ener

los to 8 ax of nercury at the lovest energies.

2

Gas Teaperature: A neen tosperature of 21°C vas used in cal~

eulations and the temperature of the laboratory varied + 1°¢ of this

ean. Therefore, the fractional error vas approxinately 4.0 percents

3r= Separation Distanes of source and detector! The error in

the noasurezent of the separation distance wis of the order of 0.8 per

conte

hem Residual Energy of the alpha partic!

This orror de the

pest Asportant in these experinents and the hardest to eotinate, How

ever, the estinate of this error

a8 reasonable fros the spread of

the exporinental data obtainod froa the energy loss apectras The ue

certainty in estiaating the poak channel of the enorcy spectra ws

Rayor powrce of erzer tn detominins the averace

At hich residual energios, the rogolution of the enerzy

systea vas vory good and the er:

Locating of the cnory

---Page Break---

spectra ume noel: » straggling of the

particles caused the enerzy spectra to broaden ent the posk could not

slble, at low renidual enerci

be Loeatod with ap euch accuracy, In this

» the error was esti-

sated to bet 2 chamela, or 0.23 per cast at Migher energtos and 5.5

Por cent at the lover residual enarctes.

Tho noct probate error of the caleulated valuen based on the

errertnaatal date wns cotersined by taking the equare root of the wu

of the equares of the naxizun fractional error in each experinent.

At higher reotdual eners!

99 the nost probable error (mean standard

deviation) found vas of the order of 4 ~ 5 parsent and 9 ~ 10 parcent

for lover residual energies respectively.

Tho valuoo proposed by the author on tho bea!

of tats snvostie

?gation for the topping power of 13 cases are given on figures 4410

to 4.13 a0 @ fimction of alpha energies} alvo, for the polecular cross

sections of atx and hytrvcarbon gee (Gly, Calg, C26, CHR, Osis)

which ere tatulated on Table def Those eroey veetion values wore

obtained fre a sssoth curves drain throuch the experimental data

Points and probable errors (figures 4.23 and 4-24) as a function of

?slpha energy; this 4s truo also for the stopping pover and range curves.

The ethod used in thie investigation gives values which are in

excellent acroonent with thous found when the gas provsure within the

chanber 19 coastant and the scurcodetactor distence ie verted?) 4a

?tho energy zezion where a eoupartoon ie possitle, ?Table 5.1 io an

exesale of cospartaan of aoleeular e:

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3 section calculations given

by pon authors fend this wrk showing 9 cood comelation within

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= 5:0 sav alla energy reston for soue hydrocarbon gases and air, This vo:

sould be extended indefinttaly for additonal cole

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gasea (ty, Copy 0, ote) given in thie work or dnstuding as

many fzorg=nic and organic research end indussrial geses aa desired,

In the cone wy, conparisons with thecrstical ealculstions using the

Bethots equation (Bq. 3+17) agros shen the residual alpha anergy 48

Aighor then 1 tov. (3

Figure 5.1).

In the radiolysie of a caseous aysten 4% 4s poositle to neasure

?the mmber of ion pairs formed by absorption of radiation. The yield of a given rea:

on ean therefore be expressed in terms of the munbor

of nolecules

30d per fon pair forced. ?The ratlo NAIL 4s commonly

referred to as the ton par yield, where M io the munber of nolecul:

changed par ion peir and Ny 1s the muster of ion paire formed. M may

desimate a opscies of a given kind dicarpoaring or being produced,

and in

zo of cases, My aay bo expressed ofther as the total

munber of ions or a9 the nusbor of fone of a given tnd, The latter

calculation 4s based ca # Imovledge of stopping pavers and the energy

required to produce en ion pel in the individual gasea, Related re

search could be developed simitancously Like ges rediolysie, deter ination of chentenl roacticn cechanigns, on ylold seasuronanta, etoy

using tho values given in this vork for inongente and hydrocarbon

azo:

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Alpha Enorey, Me

Figure 5.1 Ranzeenor:

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Seis and W:RSEAN, $.D. The Stopping Grose Sections

for Protons, O+1 to 6.0 Mev} Rav. ?ode Physs 25, 779 (1953).

BRIT, HAs: Chenteal Structures of Incrsante Gases} Je

Baue. 37, 616 (1960).

BENE, HA,

The Rango-hergy Relations Zor Slow Alpha Parti=

les and Protons in Air} Rev. Mods 2p 213 (1950).

+ GHD, Weis and POWERS, D.t Stopping Cross Sections

for Alpha Particles from 0.3 to 2.0 Movs Phys. Reve

BB, 3625 (1971).

COLARD, Js and GAL, J+ Silicon SurtacoZarrier Type Sentcon=

ductor Detectors; lucl. Instrim, Moths 16, 195 (1962)

BOURLAND, Pe

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al Acadeay of Setences ~ lletional Research Comell Publica

ton 871 (Eiited by J.W.T. Dabs and FeJe Walter), ppd?

(1961).

?JESSE, W.P. and SADADSEIS, J,

?The Range-thergy Curves for Alpha

Particles and Protons; Phys. Rev. 72, 1 (1950).

KERR, G.D., HATRR, L.

My, UNDERWOOD, MN, and WALTER,

4 Mole

cular Stopping Grose Soctions of Air, Ygy Kr, 002 and Cl,

for Alpha Particles; Health Phyo. 12, 1475 (1956)«

EMD, 5.0.1 Raddation Chentstry of Gaseas Reinhold Publishing

Corp. Yow Fors, Ne. pps 123 (496%)«

ORVILLE, WSs and THOHSS, Tet sade Spaeteye 3, $89 (1955)e

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Wee PALER, BBS Th

Stopping Power of trogen and Rydrocarbon

Vapours fer Alpha Particloy over the Energy Range 1 = 8 Mevy

Proce Fhys. Soc. 87, 681 (1966).

Y= PAULING, tt The Chenteal Ponds Comal? University Press, Ttheca

MWeEs pe 58 (1967)

Bee ROTONDT, 5.

Energy Loss of Alpha Particles in Memo; Radiation

Base 33, 1 (1968).

Vem SEGRE, B (Bitter): Brperizental Waclear Physicss vol.t, part II,

PP 166 Wileg (1953).

Wen MALAH, Pad.

Shorgy Lose of Alpha Particles, Protons and Ele

?trons in Hatter; Fh. D. Thesis, University of North Carclina,

Chapel KILL, H.C. (1962).

WEAST, RC, (BAitor): Hantbook of Chomtetay end Phystesy Cheat

eal Rubber Co., Cleveland (1966).

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TABLE At

INSTRE-STATION CAUIPMENT SETTDUS FOR EXPERDGNTS

Joe DETECTOR BISS SUPPLY

Ortec Model 423

Gate Ar 50 volta.

mR

Ortee Motel 719

Ortec Nodel 486

Coarse goin: 16 volts

Pino gaint 6.5 volts

Window: 10 volts

Lover Level: 0452 volts

tsar settings as per operating instructions.

dew Scatsn

Ortec Yodel 484

Trroshalas 0.4

Other settings as per operating instructions.

ARALOG TO DISTTAL co:TSATER

Mucloar Data

Yaro Fino: 0.10 volts

Tero Coarse: 10.0 volts.

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58

TUBE At

Coaverston Gains 102% che

Upper Level Diserisinator: 10 volte,

Lower Lovel Discrininatort 0.49 valte

other sett

as por operating instructions.

Gem MASTER couTROL

Nuclear Date

Frosot tine: 400 seconds.

Other settings es per operating instructions.

?Tom READ-TA/OUT DISPLAZ

Macloar Data

Settings as por operating instructions.

---Page Break---

TABLE A.2

ROE AND ECMOE Loos mpEanscrrat pata yor 5.477100 aT anrma

PARTICLES DN ATR

ona of Hg = MeV

os tm tam oak

10.5 1643 0.962 0.746 622 ABS

re

1669 1603 0.939 14200 557 432

3067 1644 0.963 20181 423 3629

3563, 1623 0.950 2.508 373 29

3903 1621 9.949 2792 33 2650

427 1627 06953 3.033 2 210

M7 1629 06954 36318 wz 1.00

5103 1549 06907 3a6h4 13 0.87

5360 1085 0.635 36765 R O71

5he8 36 0.002 3.893 2 0645

---Page Break---

TABLE A.3

AOSE gm Remar toss mr=noewes, pava FoR 5.477N6v ax?41 goon

PARTICLES TY i,

caasaR ?tora, CRANE = QUTVALENT

sta, comms RAN Sure ?BIEGY,

cas of Hg = We

nk 16 1.000 0.028 eg 5h

5.0. 163804954 0.355 gy 52

3.0 170.973 0.639 a5 5.01

1364 169% 04937 o.930 5 478

1k 16690972 1.236585 454,

22 1639 0.955 1.506 56 432

25eh 1628 0.954 14804 502 4.05

32h 1603 0.934 2502462 3659

36.2 1686 0.982 572 yap 3.32

ed, 1580 0.92 aur gre 2.89,

09 105 0.935 3.332 2645

5204 WI 0435 371g 1093

5307 71 0.040 3.815 at 1663

Boor a.843 - -

8 04004 3.986 179 1.39

104000 4227434 1.02

10,000 kez70 8 0.65,

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TABLE AL

SANOZ AND DWERGY 10SS EXPEROENTAL DATA FoR 5.47-¥EV an arena

PARTICLES Di Cig

cmeen ora, can, EQUIVALENT

rasssuss, courts, «ATO Inte za, ?ENERO,

eas of Hg os Mav

oe 1663 0.999 0,056 698 Seka

36 1602 0495004255662 5h

10 1636 06974 a ho82

907 1685 1.000 ons 586 455

127 1583 0.999 got 542 bez

1564 1584 0.940 14093505 3692

18.6 168 06954 14320 ass 355

216 1518 0.936 14533408 3.17

2b 20.956 6353 2.1

2.0 Kb 0.976 4.968 a7 245

316 1567 0918224319 148

3h8 ee 0.408 KB 0.56

3504 58 00m 25133 0433

36.0 © 0,000 24556 5 0.19

---Page Break---

TABLE a5

RANGE aD ENERGY Loss EXPERDENTAL para POR 5.47-NEV An2%1 ana

cE

PRessuas,

esa of Be

1.0

3.0

25.5

26.3

?ror,

cours

1613

1631

163

1643

15%

1604

1565

1952

us?

1430

546

202

1

RATIO

0.959

1.000

06965

oom

0.949

0.954

0.930

04923

ong

04850

06324

0.120

0.000

PARTICLES TX O3iig

ee

o.071

0.355

0.540

ov7e8

1.072

1s

148

46541

1.669

ame

1.769

nen

1.850

cae

BER

693

623

573

503,

an

35h

224

uo

2

65

8

BqUIvALENT

?Bier,

Mev

5638

8h,

eks

3490

3.20

2.75

2.20

wn

1.08

0.95

ont

0450

oont

---Page Break---

TABLE 6,

RKRS AND BRmey 109s exrsenc:

PAXTIOI

ral DATA FOR 5.4.77 an%47 popag

Ti Cait,

Ri TOME cum, agora

cE, COUNTS RATION yp, © NRE ?BIEAGT

% Ea Mev

07 1699 0.990 0.049 m2 5eh5

29 WHS 4.000 0.206 69 5.27

509 1705 049% 0.419 as 5.04

89 Wet 04980 0.632 616 4

19 1682 0.900 0,045 sz 452

Med 1604 04935 1.058 33 heat

12.0 168104980 1.207 504 3.98

21.0 W641 04956 14492 465 3662

200 1680 0.989 44705 re) 3.28

21.0 Wis 0.960 1.918 380 2.95

30.0 15610910 291 325 252

33.2 162004980 24358 267 2.07

36.0 1503 0.876557 206 1.60

3700 15K5 0,900 2.608 m4 1635

3807 150604878 a9 190 4.01

4004 1254 O71 2.849 88 0.68

4009 200 0.116 2.906 5h ona

43 0.012 2.934 52 040

au? 10,0005 2.962 x» 0.23

---Page Break---

LE 7

RAWE AKD EER 1089 DOAROGTAL DATA FOR 5-4 7-30V an41 arpea

canaER

FRESSIRE,

ens of Ez

0.8

38

68

38

128

15.9

18.9

2109

25.0

21.0

2.8

Bh

28.8

RATIO

1.000

O.9h4

0.959

04985

0.976

0.981

0.962

04943

04932

ow7es

0.207

0.002

0.000

PARTICLES Dt Cg

Tatpy

eae

0.056

0.270

04483

04696

04909

1.129

1.343

16555

177%

1918

1.915

2.017

2.046

cue,

HOGER

6%

653

oo

550

494,

431

360,

186

105

R

32

SquaaT

'RIERGY,

Mev

Soh

5.07

467

beet

3683

3634,

2.79

2.28

ohh

0.81

0655

0624,

0615

---Page Break---

SE AND

oO?

Det

67

10.1

1363

1669

20.8

25.8

324

Bue?

38

35.7

36.1

369

TUBULE 8

Y L083 EAPERDSEMAL ATA FoR 5.4770 aT arena

TOTAL

cours

16

1706

1670

167

1653

1685

1619

1565

1592

1532

1399

s92

153

10

2

PARTICLES TH 0

RATIO

0.991

012

0.991

04993

0.981

1-000

0.960

0.950

0.945

0.910

04830

0.707

0.090

0.005

0.000

94050

04220

06476

ont

0.945

1.200

wart

1.833,

1.925

2.280

2.420

2.472

2.536

2.565

24621

REER

699

667

62

sm

530

45

27

on

169

109

92

&

49

BRUIvalrr

?BIERGY,

Xe¥

50h

5018

4083

hel

an

3668

3624,

2.67

2.10

4.31

0684,

ont

0652

0.38

0.20

65

---Page Break---

1528

1454

120

TABLE A.9

ISLES TW 02

RATIO

1.007

0.995

0.957

04959

o.ous

1.009

0.958

ome

0.960

04970

068%

0.901

04904

0.860

0.275

0.071

0,000

cua,

RBI

703

232

133

DATA FOR 5.47=RCV An°%47 aupna

EQUEVALST

?BERY,

Nov

Sekb

53h

5.06

4480

bokh

beth,

38h,

308

3605

2.70

2.16

1.80

1.07

0.87

0656

0.42

0.26

---Page Break---

88

m8

8

2.8

32.8

Ih

41.0

45.0

Mae

506

52.0

5208

5309

5563

5548

56.2

1697

1758

1688

1652

1588

1624

1567

1651

1607

1626

16%

1560

1513

173

ea)

1939

389

?TABLE a-10

RATIO

1.000

1.035

06994

0.973

0.935

0.956

04923

0.973

0.947

04964

0.951

0.919

0.891

0.9%

on8e3

0.789

6dr

o.217

0,010

0.001

Tater

0.056

0.341

0.625

1.051

1.477

1.762

2.046

24330

2.657

2.913

2197

36467

34595

34694

3.751

3.829

3.826

3.929

3.964

3.993

msm

705

or

67

590

53h,

496

458

412

361

3h

203

m

138

1%

a2

n

56

ar

S2ITAL DATA FOR 5047-4 ant apna

PQUIVALET

BHEROY,

Mav

Soll?

5622

9h,

458

hath

3.85

3655

3.20

2.80

2043

2,02

157

1033

1.07

O97

0.76

0463

0655

0643

0.36

67

---Page Break---

5545

5643

5965

599

TaBte At

EPrEnm

PARTTSISS

Tra

Xstor

o.170

06454

o.n7

1.001

146342

1.612

1.911

2.223

2.479

2.263

36133

36431

3.701

e255

crane,

mma

690

659

598

559

523

182

125

102

52

TAL DATA FOR 5.,77%MEV An? urna

EQUIVALENT

?BERGE,

Mev

5636

512,

487

dob

beh,

4.06

31h

Bet

3et2

2663

2.20

1.87

et

om

0.79

0654,

0440

0.20

---Page Break---

TABLE At?

04998

0.970

1.000

0.980

0.994

0.974,

o.o71

04959

o.g71

0.934

0.907

0.927

0.919

o.922

0.892

04566

0.025

0.000

?a

0.028

0.099

0.227

0.362

06518

06675

nese

1.072

1.321

1.463

16

1748

1918

207

26344

2.499

2.570

2.644

came,

UGE

700

687

669

640

615

588

505

BRR ERS

1st

22

56

SRESTTAL DATA POR S477 aT gpa

PARTICLES TN Op

PQUIVALETT

?SERGY,

av

5h

5633

5.18

4

am

4456

422

3.92

3655

69

---Page Break---

TABLE 2.13

PAIGE 27D EVEGY Loss E@IMETAL para Por 5.47ev An? appmy

PARTICLES Tt Ee

cana

PRESSURE,

cas of Ee

O64

bok

94

Boo

18.9

25

22

31.0

33.0

35.0

3569

3667

3803

rom

conts

1657

1687

1662

1662

1567

Mah

104

conn a 8 ER

RATIO

0.982

1.000

04985

0.985

0.928

0.880

0.832

0.798

06138

0.017

0.004

0.000

(0.000

0.000

0.000

?stor

0.028

04312

0646

0.987

16342

1.669

1.932

2202

26344

26415

26486

2.550

2.607

a1

2.842

cua,

OS

4,

SQUIvALErT

?BERG,

Mev

Solet

5.08

4063

hts

3.67

3.1%

2%,

2.20

1684

?7

1.60

1643

1.30

1404

0463

---Page Break---

8

38

68

10.1

12.9

15.9

18.7

19.8

200k

21.0

RY Less

ror

TABLE etd

SPERD IAL pan

PARTICLES Tr

cours ?Rarro

1679

1683

1645

1656

1630

1625

154k

103

112

0.968

04965

0.917

o.714

01086

(0.000

ron s.c77?v an arpa

693

3662

2.96

217

116

0.70

648

0.25,

n

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