

4. Mirujoč elektron damo v homogeno električno polje z jakostjo 2,75 kV/m. Kolikšno pot preteče elektron v 2  $\mu$ s? Kolikšna je tedaj njegova kinetična energija?

30.6.P4

str/47(K)  
str/54(K)

$$E = 2,75 \text{ kV/m}$$

$$t = 2 \mu\text{s}$$

$$\frac{dp}{dt} = \frac{d(m\gamma v)}{dt} = eE \Rightarrow m\gamma v = eEt \Rightarrow$$

$$\Rightarrow \frac{mv}{\sqrt{1 - \frac{v^2}{c^2}}} = eEt \quad / : mc \Rightarrow \frac{v/c}{\sqrt{1 - (\frac{v}{c})^2}} = \frac{eE}{mc} t = \alpha t \Rightarrow$$

$$\Rightarrow \left(\frac{v}{c}\right)^2 = \alpha^2 t^2 \left[1 - \left(\frac{v}{c}\right)^2\right] = \alpha^2 t^2 - \alpha^2 t^2 \left(\frac{v}{c}\right)^2 \Rightarrow$$

$$\Rightarrow \left(\frac{v}{c}\right)^2 \left[1 + \alpha^2 t^2\right] = \alpha^2 t^2 \Rightarrow$$

$$\frac{v}{c} = \frac{\alpha t}{\sqrt{1 + \alpha^2 t^2}}$$

$$s = \int_0^t v dt = c \int_0^t \frac{\alpha t dt}{\sqrt{1 + \alpha^2 t^2}} = c \int_1^u \frac{\alpha \cdot \frac{1}{\alpha} du}{2\alpha^2 t \sqrt{u}} = \frac{c}{2\alpha} \int_1^u \frac{du}{\sqrt{u}} = \frac{c}{2\alpha} \cdot 2 \sqrt{u} \Big|_1^u \Rightarrow$$

$$v = \alpha^2 t^2 + 1 \quad du = 2\alpha^2 t dt \Rightarrow dt = du / 2\alpha^2 t$$

$$s = \frac{c}{\alpha} \left[ (\alpha^2 t^2 + 1)^{1/2} - 1 \right] = 2,375 \cdot \frac{3 \cdot 10^8}{1,611 \cdot 10^6} = 442 \text{ m}$$

$$\alpha = \frac{eE}{mc} = \frac{1,6 \cdot 10^{-19} \cdot 2,75 \cdot 10^3}{9,1 \cdot 10^{-31} \cdot 3 \cdot 10^8} = \frac{1,611 \cdot 10^{-17}}{10^{-23}} = 1,611 \cdot 10^6 \text{ s}^{-1}$$

$$\alpha^2 = 2,5946 \cdot 10^{12}$$

$$\alpha^2 t^2 = 10,3804$$

$$\sqrt{\alpha^2 t^2 + 1} = 3,375$$

$$\Delta W = \Delta T_{\text{el}} = e \int E v dt = e \int E ds = e E s = mc^2 (\gamma - 1)$$

$$\Delta T_{\text{el}} = T_{\text{el}} = e E \cdot s = 1,946 \cdot 10^{-13} \text{ J} = 1,216 \text{ MeV}$$

$$1,6 \cdot 10^{-19} \cdot 2,75 \cdot 10^3 \cdot 442 = 1,946 \cdot 10^{-13} = 1,946 \cdot 10^{-13} \text{ J}$$

$W_0 = 0,511 \text{ MeV}$   
 $W = 2,763 \cdot 10^{-13}$   
 $P = 8,2 \cdot 10^{-22}$   
 $P = m\gamma v = eEt$   
 $W = \sqrt{W_0^2 + P^2}$   
 $T = W - W_0$

A-L

1882

1. V začetku mirujoč dvakrat ioniziran helijev ion preleti napetost 6 GV preden prileti v homogeno magnetno polje z gostoto  $B = 1 \text{ T}$  tako, da je kot med vektorjema hitrosti in magnetnega polja  $90^\circ$ .
- Koliko časa potrebuje helijev ion za en obhod?

$$m \sim 4 \text{ a.e.m}$$

$$m_p c^2 = 938 \text{ MeV}$$

$$m c^2 \sim 375 \text{ GeV}$$

$$e = 2e_0, \quad B = 1 \text{ T}, \quad U = 6 \text{ GV}$$

$$\frac{d(m_{\text{rel}} v)}{dt} = e v B$$

$$T = 2e_0 \cdot U = 12 \text{ GeV}$$

$$m_{\text{rel}} a = e v B$$

$$m_{\text{rel}} \frac{v^2}{r} = e v B, \quad \omega = \frac{v}{r} = \frac{2\pi}{t_0}$$

$$\omega = \frac{v}{r} = \frac{2\pi}{t_0}$$

$$\Rightarrow m_{\text{rel}} \left( \frac{v}{r} \right) = e B \Rightarrow m_{\text{rel}} \left( \frac{2\pi}{t_0} \right) = 2e_0 B \Rightarrow t_0 = \frac{m_{\text{rel}} \pi}{e_0 B} = \frac{m_{\text{rel}} c^2 \pi}{e_0 B \cdot c^2} =$$

$$m_{\text{rel}} c^2 = T + m c^2$$

$$= \frac{(T + m c^2) \pi}{e_0 B \cdot c^2} = 5,5 \cdot 10^{-7} \text{ s}$$

M-Ž

1882

2. V začetku mirujoč dvakrat ioniziran helijev ion preleti napetost 8 GV preden prileti v homogeno magnetno polje z gostoto  $B = 1,5 \text{ T}$  tako, da je kot med vektorjema hitrosti in magnetnega polja  $90^\circ$ .
- Kolikšna je ukrivljenost tira po katerem se začne gibati helijev ion?

$$U = 8 \text{ GV}$$

$$B = 1,5 \text{ T}$$

$$\frac{1}{r} = ?$$

$$T = 2e_0 \cdot U = 16 \text{ GeV}$$

$$\frac{d(m_{\text{rel}} v)}{dt} = e v B \Rightarrow m_{\text{rel}} \frac{v^2}{r} = e v B \Rightarrow$$

$$W_0 \approx 4 m_p c^2 = 3,75 \text{ GeV}$$

$$\Rightarrow P = m_{\text{rel}} v = e r B \Rightarrow \frac{1}{r} = \frac{e B}{P}$$

$$\frac{1}{r} = \frac{2 \cdot e_0 \cdot B \cdot c}{\sqrt{2 T W_0 + T^2}} = 0,0464 \text{ m}^{-1}$$

$$W^2 = (T + W_0)^2$$

$$W^2 = c^2 P^2 + W_0^2$$

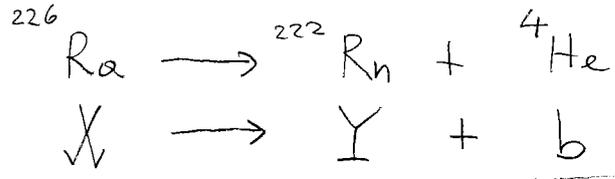
$$0 = c^2 P^2 - T^2 - 2 T W_0$$

$$P = \frac{1}{c} \sqrt{2 T W_0 + T^2}$$

21, 11 -

1992

4. Mirujoče jedro  $^{226}\text{Ra}$  preide v jedro  $^{222}\text{Rn}$  in pri tem odda delec  $\alpha$ .  
 Mase  $^{226}\text{Ra}$ ,  $^{222}\text{Rn}$  in  $\alpha$  so po vrsti 226,02536, 222,01753 in 4,00260  
 a.e.m.. Kolikšna je hitrost delca  $\alpha$  po razpadu? 25.9.



$$m_x c^2 = m_Y c^2 + m_b c^2 + \frac{m_Y v^2}{2} + \frac{m_b v^2}{2}$$

$$\frac{m_Y v^2}{2} + \frac{m_b v^2}{2} = |Q| = (m_x - m_Y - m_b) \cdot c^2 = 4,87 \text{ MeV}$$

$$m_Y v_Y + m_b v_b = 0$$

$$v_Y = - \frac{m_b}{m_Y} \cdot v_b$$

$$v_b = \sqrt{\frac{2|Q|}{m_b} / \left[1 + \frac{m_b}{m_Y}\right]} = 1,52 \cdot 10^7 \frac{\text{m}}{\text{s}}$$

26.11

5. Z radioizotopom  $\text{Co}^{60}$  obsevamo pacienta. 1 cm pod kožo v tkivu je dobil dozo 100 radov (1 rad = 0.01 J/kg). Kolikšna je bila doza 3 cm globoko v tkivu, če je absorpcijski koeficient za tkivo pri  $\text{Co}$  gama žarkih  $0.031 \text{ cm}^{-1}$ ?

$$D_1 = D_0 e^{-\mu x_1}$$

$$D_3 = D_0 e^{-\mu x_3}$$

$$x_1 = 1 \text{ cm}$$

$$x_3 = 3 \text{ cm}$$

$$\mu = 0.031 \text{ cm}^{-1}$$

$$D_1 = 100 \text{ rad}$$

$$\frac{D_3}{D_1} = e^{-\mu(x_3 - x_1)}$$

$$D_3 = D_1 e^{-\mu(x_3 - x_1)}$$

$$= 100 e^{-0.031 \cdot 2}$$

$$= 94 \text{ radov}$$

$$94 \cdot 10^{-2} \text{ J/kg}$$

3. Aktivnost nekega radioaktivnega izvora, ki emitira delce  $\alpha$  z energijo 5 MeV, je  $7 \cdot 10^9$  razpadov v sekundi. Izračunaj, koliko časa mora ostati izvir v tumorju, da bo le ta prejel dozo 20 J/kg. Masa tumorja je 1 kg. Predpostavimo, da se aktivnost izvora med obsevanjem ne spremeni.

185p3

$$W_{\alpha} = 5 \text{ MeV}$$

$$A = 7 \cdot 10^9 \text{ s}^{-1}$$

$$D = 20 \text{ J/kg}$$

$$m = 1 \text{ kg}$$

$$t = ?$$

$$N = N_0 e^{-\lambda t}$$

$$A = -\frac{dN}{dt} = +\lambda N_0 e^{-\lambda t} \approx \text{konst}$$

$$\boxed{\Delta N = A \cdot t}$$

↑  
st. resp. jeder

$$D = \frac{\Delta N \cdot W_{\alpha}}{m} = \frac{A \cdot t \cdot W_{\alpha}}{m}$$

⇓

$$t = \frac{D \cdot m}{A \cdot W_{\alpha}} = \underline{\underline{3571 \text{ s} \approx 1 \text{ ura}}}$$

19. Za koliko će se promeniti vrednost prekidnog napona fotoelektrične struje ako se talasna dužina svetlosti koja izaziva fotoelektrični efekt na fotokatodi smanji od  $\lambda = 402 \text{ nm}$  na  $\lambda = 400 \text{ nm}$ ?

- a) 12,8 mV
- b) 8,7 mV
- c) 15,5 mV**
- d) 3,2 mV
- e) ni jedan od gornjih rezultata nije tačan

$$\Delta \lambda = 400 - 402 = -2$$

$$W_k = h\nu - W_0 = eU$$

$$dW_k = h d\nu = e dU$$

19)

$$h d\nu = -h \frac{c}{\lambda^2} d\lambda = dE_{kmax} = e dU$$

$$c = \lambda \nu$$

$$\nu = \frac{c}{\lambda}$$

$$d\nu = -\frac{c}{\lambda^2} d\lambda$$

$$\Delta U = -\frac{hc}{e\lambda^2} \Delta \lambda$$

$$\Delta \lambda = -2 \text{ nm}$$

$$\Delta U = \frac{6,62 \cdot 10^{-34} \cdot 3 \cdot 10^8}{1,6 \cdot 10^{-19} \cdot 16 \cdot 10^4 \cdot 10^{-18}} \cdot 2 \cdot 10^{-9}$$

$$= \frac{6,62 \cdot 3 \cdot 2}{1,6 \cdot 16} \cdot \frac{10^{-35}}{10^{-37}} = 1,55 \cdot 10^{-3} \text{ V} = \underline{\underline{15,5 \text{ mV}}}$$

$$h = 6,62 \cdot 10^{-34}$$

$$c = 3 \cdot 10^8$$

$$e = 1,6 \cdot 10^{-19}$$



5. Sprememba valovne dolžine fotonov z energijo 60 keV pri interakciji s slabo vezanimi elektroni je enaka Comptonovi valovni dolžini  $\lambda_c = h/(m_e \cdot c)$ . Kolikšna je kinetična energija elektrona po interakciji? Pod katerim kotom se razhajata elektron in foton po interakciji?

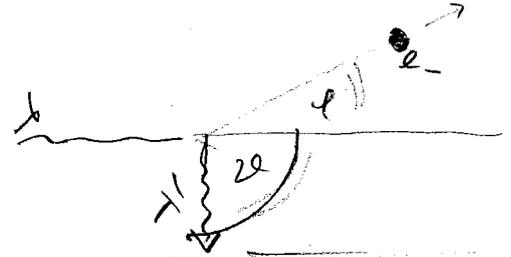
1853

$$h\nu = 60 \text{ keV}$$

$$\lambda' - \lambda = \lambda_c \Rightarrow \vartheta = 90^\circ$$

$$m_e c^2 = 0.51 \text{ MeV}$$

$$\vartheta = 90^\circ$$



$$\lambda' - \lambda = \lambda_c (1 - \cos \vartheta) \quad \vartheta = 0$$

$$\theta = \varphi + \vartheta = ?$$

$$E_k = ?$$

$$c = \nu \lambda$$

dr. polne energije:

$$m_e c^2 + h\nu = m_e c^2 + E_k + h\nu'$$

$$E_k = h\nu - h\nu' = h\nu \left( 1 - \frac{m_e c^2}{m_e c^2 + h\nu} \right) =$$

$$= h\nu \left( \frac{h\nu}{m_e c^2 + h\nu} \right) = \frac{h\nu}{1 + \frac{m_e c^2}{h\nu}} = \underline{\underline{6.3 \text{ keV}}}$$

$$W^2 = c^2 p^2, \quad W = c p = h\nu \Rightarrow p = \frac{h\nu}{c} = \frac{h}{\lambda}$$

obranitar gib. količine:

$$y\text{-os: } \frac{h}{\lambda'} = p_e \cdot \sin \varphi$$

$$x\text{-os: } \frac{h}{\lambda} = p_e \cos \varphi$$

$$\frac{\lambda}{\lambda'} = \tan \varphi \Rightarrow \tan \varphi = \frac{m_e c^2}{m_e c^2 + h\nu}$$

$$\varphi = \arctan \frac{m_e c^2}{m_e c^2 + h\nu} = \underline{\underline{41,8^\circ}}$$

$$\theta = \varphi + \vartheta = \underline{\underline{131,8^\circ}}$$

$$\lambda' = \lambda + \frac{h}{m_e c}$$

$$\frac{c}{\nu'} = \frac{c}{\nu} + \frac{h}{m_e c}$$

$$\frac{c}{\nu'} = \frac{m_e c^2 + h\nu}{\nu m_e c}$$

$$h\nu' = \frac{h\nu \cdot m_e c^2}{m_e c^2 + h\nu}$$

$$\frac{\nu'}{\nu} = \frac{\lambda}{\lambda'} = \frac{m_e c^2}{m_e c^2 + h\nu}$$

3. Eden izmed fotonov, ki nastane pri anihilaciji mirujočega pozitrona in mirujočega elektrona, se Comptonso sipa pod kotom  $90^\circ$  glede na njegovo vpadno smer. (Kolikšen je radij kroga, ki ga opiše izbiti elektron v ravnini, ki je pravokotna na magnetno polje) gostote  $10^{-3}$  T? **Racunaj relativistično!** *Kolikšno je gib. količina elektrona? ← dodal se vaji*

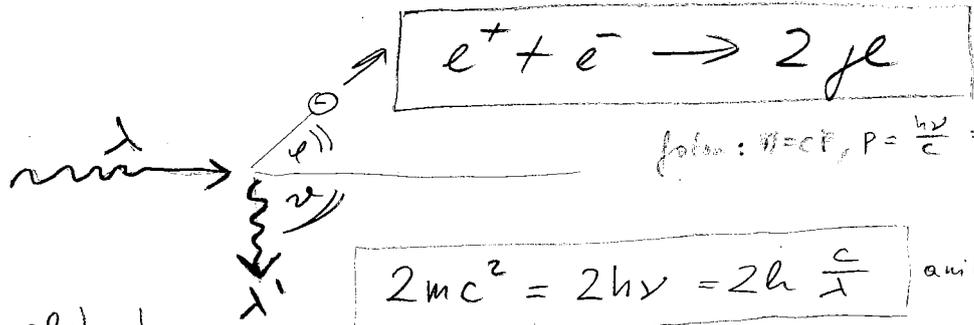
$$B = 10^{-3} \text{ T}$$

$$\vartheta = 90^\circ$$

$$\lambda_c = 0,0024 \text{ nm}$$

$$\lambda' - \lambda = \lambda_c (1 - \cos \vartheta) = \lambda_c$$

$$\lambda' = 0,00483 \text{ nm}$$



$$2mc^2 = 2h\nu = 2h \frac{c}{\lambda} \quad \text{anihilacija}$$

$$\lambda = \frac{h}{mc} = 0,00243 \text{ nm}$$

okrajševanje gibalne količine:

$$x\text{-os: } \frac{h}{\lambda} = m\gamma v \cos \varphi$$

$$y\text{-os: } \frac{h}{\lambda'} = m\gamma v \sin \varphi$$

$$\left(\frac{h}{\lambda}\right)^2 + \left(\frac{h}{\lambda'}\right)^2 = m^2 \gamma^2 v^2$$

kroženje:

$$\frac{d(m\gamma v)}{dt} = e v B$$

$$m\gamma \frac{v^2}{r} = e v B$$

$$m\gamma v = e r B$$

$$r = \frac{m\gamma v}{e B}$$

$$r = \frac{m\gamma v}{e B} = \frac{h}{e B} \sqrt{\left(\frac{1}{\lambda}\right)^2 + \left(\frac{1}{\lambda'}\right)^2} = 1,91 \text{ m}$$

2. Od fotonov, ki padajo na katodo fotocelice, v povprečju samo vsak sesti izbija elektron. Kolikšen nasičen električen tok teče skozi fotocelico, če pada na njeno katodo svetlobni tok 10 W z valovno dolžino 405 nm?

1992

(ali je to vredost energije (hv) za izbitje elektrona?)

$$\tilde{n} = \frac{dN}{dt} \quad [s^{-1}]$$

$$P = \tilde{n} \cdot h\nu$$

$$\lambda = 405 \text{ nm}$$

$$h = 6,63 \cdot 10^{-34} \text{ Js}$$

$$c = \nu \lambda$$

$$W_k = h\nu - W_{izst}$$

$$\nu = c/\lambda$$

$$P = \tilde{n} \cdot h \frac{c}{\lambda}$$

$$\frac{P \lambda}{h \cdot c} = \tilde{n}$$

$$I = \frac{de}{dt} = \frac{d(N \cdot e)}{dt} = \frac{1}{6} \tilde{n} \cdot e_0 = \frac{1}{6} \cdot \frac{P \cdot \lambda \cdot e_0}{h \cdot c} = \underline{\underline{0,14 \text{ A}}} \quad (2)$$



6. Na kovinsko ploščico z izstopnim delom 3.5 eV pada snop svetlobe z valovno dolžino 90 nm. Ploščica je v vakuumu in v homogenem magnetnem polju z gostoto 0.0016 T. Magnetno polje je vzporedno s ploščico. Kolikšen je maksimalni polmer tira po katerem se lahko gibajo izbiti elektroni ?

1895

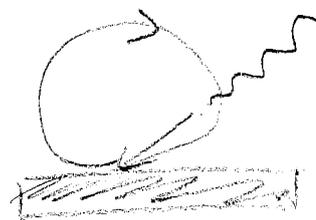
$$W_0 = 3,5 \text{ eV}$$

$$\lambda = 90 \text{ nm}$$

$$B = 0,0016 \text{ T}$$

$$m_e = 9,1 \cdot 10^{-31} \text{ kg}$$

$$h = 6,62 \cdot 10^{-34} \text{ Js}$$



$$W_k = h\nu - W_0$$

$$\frac{mv^2}{2} = \frac{hc}{\lambda} - W_0$$

$$v = \sqrt{\frac{2}{m} \left( \frac{hc}{\lambda} - W_0 \right)} \approx 2 \cdot 10^6 \frac{\text{m}}{\text{s}}$$

kroženje v mag. polju

$$e v B = m \frac{v^2}{r}$$

$$e B r = m v \Rightarrow$$

$$r = \frac{m v}{e B}$$

$$r = 16,8 \cdot 10^{-3} \text{ m}$$

$$\frac{10^3 \cdot 10^{-31} \cdot 10^6}{1,6 \cdot 10^{-19}}$$

3. Curek počasnih elektronov, ki jih pospešimo z napetostjo 54 V, usmerimo pravokotno na površino kristala v katerem so vrste ionov v razmiku 0,215 nm. Počasni elektroni se odbijajo od površine kristala in ne prodrejo v njegovo notranjost. Razmere so podobne kot pri interferenci svetlobe na uklonski mrežici. Pod katerim kotom se pojavi prvi ojačani curek odbitih elektronov?

2 to  
2

1993

$$h = 6.62 \cdot 10^{-34} \text{ Js} \quad m_{e1} = 9.1 \cdot 10^{-31} \text{ kg}$$

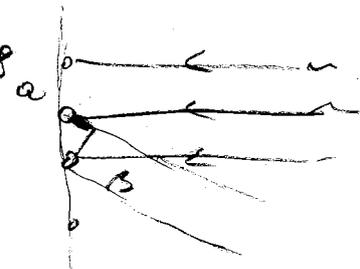
$$c = \nu \lambda$$

$$U = 45 \text{ V}, \quad a = 0,215 \text{ nm}, \quad m = 9,1 \cdot 10^{-31} \text{ kg}$$

$$\text{foton: } W^2 = c^2 P^2 \Rightarrow P = \frac{W}{c} = \frac{h\nu}{c} = \frac{h}{\lambda}$$

de Broglie:  $P = mv = \frac{h}{\lambda_B} \Rightarrow \lambda_B = \frac{h}{mv}$   
 ze delce

$$\frac{mv^2}{2} = e_0 U \Rightarrow v = \sqrt{\frac{2e_0 U}{m}} \Rightarrow mv = \sqrt{2m e_0 U}$$



$$\Delta x = a \sin \beta = N \lambda$$

$$N=1: \underline{a \sin \beta = \lambda}$$

$$\lambda_B = \frac{h}{\sqrt{2m e_0 U}}$$

N=1:

$$a \sin \beta = \lambda_B \Rightarrow \sin \beta = \frac{\lambda_B}{a} = \frac{h}{a \sqrt{2m e_0 U}} \Rightarrow$$

$$\beta = \arcsin \left[ \frac{h}{a \sqrt{2m e_0 U}} \right] = \underline{0.85^\circ}$$

1. Mirujoč pozitron damo v homogeno električno polje z jakostjo 3 kV/m. Kolikšno pot napravi pozitron v prvih 3  $\mu$ s? Računajte relativistično!

$$E = 3 \text{ kV/m}$$

$$t = 3 \mu\text{s}$$

$$\frac{dp}{dt} = \frac{d(m\gamma v)}{dt} = eE \Rightarrow m\gamma v = eEt \Rightarrow \frac{m\gamma v}{\sqrt{1 - \frac{v^2}{c^2}}} = eEt \Rightarrow$$

$$\Rightarrow \frac{v}{c} = \frac{\alpha \cdot t}{\sqrt{1 + \alpha^2 \cdot t^2}}, \quad \alpha = \frac{e \cdot E}{m \cdot c}$$

$$s = \int_0^t v dt = c \int_0^t \frac{\alpha t dt}{\sqrt{1 + \alpha^2 \cdot t^2}} = \frac{c}{\alpha} \left[ (\alpha^2 t^2 + 1)^{1/2} - 1 \right] = \underline{745 \text{ m}}$$

$u = \alpha^2 t^2 + 1$

$$\alpha = \frac{1.6 \cdot 10^{-19} \cdot 3 \cdot 10^3}{9.1 \cdot 10^{-31} \cdot 3 \cdot 10^8} = 1.758 \cdot 10^6$$

$$\alpha t = 5.274$$

**naloga** Pozitron s  $W_2 = 20 \text{ MeV}$  sreča mirujoči elektron in se z njim v letu annihilira. Zanimajo se različni delci energiji nastalih žarkov  $\gamma$ , od katerih eden odleti v smeri leta pozitrona, drugi pa v nasprotni smeri?

chr. gib količine:  $P = \frac{h\nu}{c_0} - \frac{h\nu'}{c_0}$

$$c_0 P = h(\nu - \nu')$$

$\Downarrow$

$$h(\nu - \nu') = \sqrt{W_2^2 + 2W_2 W_0}$$

$$= \underline{20.5 \text{ MeV}}$$

$$\oplus \rightarrow \ominus \quad | \quad \xleftarrow{\nu'} \quad \xrightarrow{\nu}$$

$$W^2 = W_0^2 + c_0^2 P^2$$

$$W^2 = (W_e + W_0)^2$$

$$0 = -c_0^2 P^2 + W_2^2 + 2W_2 W_0$$

$$c_0^2 P^2 = W_2^2 + 2W_2 W_0$$

$$c_0 P = \sqrt{2W_2 W_0 + W_e^2}$$

$$W_p = 938 \text{ MeV}$$

18.11.1942

7. V pospeševalniku dobimo protone s kinetično energijo 5900 MeV.

Kolikšna je njihova hitrost?

$$m_p = 1,672 \cdot 10^{-27} \text{ kg}$$

FZ

$$W_E = m_p c_0^2 - m c_0^2 = m c_0^2 \left( \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} - 1 \right)$$

$$\frac{W_E}{m c_0^2} + 1 = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$$1 - \frac{v^2}{c^2} = 1 / \left( 1 + \frac{W_E}{m c_0^2} \right)^2$$

$$v = c_0 \left( 1 - \frac{1}{\left( 1 + \frac{W_E}{m c_0^2} \right)^2} \right)^{1/2} = 0,928 \cdot c_0 =$$
$$= \underline{\underline{2,786 \cdot 10^8 \text{ m/s}}}$$

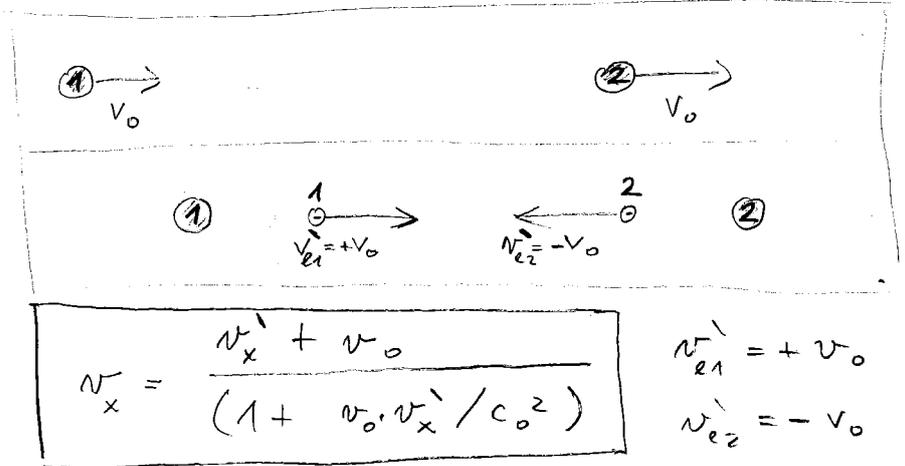
$$m_p c_0^2 = 938 \text{ MeV}$$

p. Džepni CPP1

5. Dva radioaktivna iona s pospeševalnikom pospešimo do hitrosti  $0,9 \cdot c_0$ . Iona se gibljeta drug za drugim po isti premici. V nekem trenutku vsako od jeder obeh ionov odda po en elektron s hitrostjo  $0,9 \cdot c_0$  v sistemu gibajočih se ionov v smeri proti drugemu jedru. Izračunaj kinetični energiji obeh elektronov v sistemu pospeševalnika?

$$v_0 = 0,9 \cdot c_0$$

$S \equiv$  lab. sistem  
 $S' \equiv$  sistem ionov



$$v_{e1} = 2v_0 / (1 + v_0^2/c_0^2) = \frac{1,8 c_0}{(1 + 0,81)} = \underline{\underline{0,9945 c_0}}$$

$$v_{e2} = 0$$

$$W_{1/2} = W - W_0 = mc_0^2(\gamma - 1), \quad \gamma = (1 - \frac{v^2}{c^2})^{-1/2} = 9,5263$$

$$W_{2e1} = \underline{\underline{6,98 \cdot 10^{-13} \text{ J}}} = \underline{\underline{4,36 \text{ MeV}}}$$

$$\underline{\underline{W_{2e2} = 0}}$$

$$v_x' = \frac{(v_x - v_0)}{(1 - \frac{v_0 v_x}{c_0^2})}$$

Delca se gibljata drug proti drugemu s hitrostima  $\frac{3}{5}c_0$  in  $\frac{4}{5}c_0$ . Kaksna je medsebojna relativna hitrost delcev?

$$v_1 = \frac{3}{5}c_0$$

$$v_2 = \frac{4}{5}c_0$$



$$ct = \gamma_0(ct' + \frac{v_0}{c_0}x')$$

$$x = \gamma_0(x' + \frac{v_0}{c_0}ct')$$

diferenciral  $\Rightarrow v_x = \frac{dx}{dt} \dots$



četrvec:

$$(ct, x, y, z) = \underline{x}$$

$-c_0^2t^2 + x^2 + y^2 + z^2 = \text{invarianta}$   
 ↑  
 minus

skalarni produkt  $\equiv x^T [p] x$

$$[p] = \begin{bmatrix} -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad \underline{x}^T = (ct, x, y, z)$$

$$\underline{x} = \begin{pmatrix} ct \\ x \\ y \\ z \end{pmatrix}$$

$$\Delta v = (v_1 + v_2) / (1 + \frac{v_1 v_2}{c_0^2}) =$$

=

$$v'_x = \frac{(v_x - v_0)}{(1 - \frac{v_0 v_x}{c_0^2})}$$

5) He<sup>2+</sup> ion

Dvakrat ioniziran helijev ion preleti napetost  $10^9$  V in prileti v homogeno magnetno polje gostote 1.5 T, tako da je kot med vektorjema hitrosti in magnetnega polja  $90^\circ$ . Kolikšen je obhodni čas iona v magnetne polju?

$$B = 1.5 \text{ T}$$

$$T = 2e_0 U = \underline{\underline{18 \text{ GeV}}}$$

$$\underline{\underline{mc^2 = 4m_{\text{d.m.}} c^2 \approx 3.75 \text{ GeV}}}$$

$$t_0 = \frac{(T + mc^2) \pi}{e_0 B \cdot c^2} =$$

$$\frac{21.75 \times 10^9 \times 1.6 \times 10^{-19} \pi}{1.6 \cdot 10^{-18} \cdot 1.5 \cdot 9 \cdot 10^{16}} = \frac{21.75 \cdot \pi}{9 \cdot 1.5} 10^{-7} \text{ s} =$$

$$= \underline{\underline{5.06 \cdot 10^{-7} \text{ s}}}$$

$$\frac{d(m\gamma \vec{v})}{dt} = 2e_0 \vec{v} \times B$$

$$m\gamma \frac{d\vec{v}}{dt} = 2e_0 \vec{v} \times B$$

$$\text{magl } \frac{v}{r} = 2e_0 v B$$

$$m\gamma \frac{v}{r} = 2e_0 v B$$

$$\boxed{\omega = \frac{2\pi}{t_0}} \quad \boxed{\omega = \frac{v}{r}}$$

$$m\gamma \frac{2\pi}{t_0} = 2e_0 v B$$

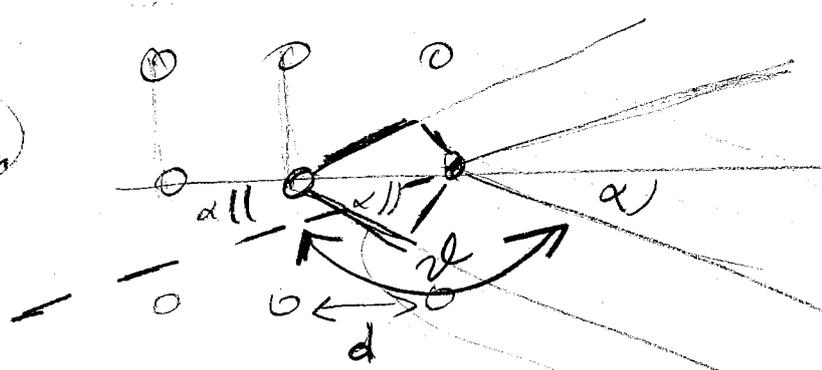
$$t_0 = \frac{\pi m\gamma \cdot c^2}{e_0 B \cdot c^2} = \frac{\pi W}{e_0 B c^2} = \frac{\pi (T + W_0)}{e_0 B c^2}$$

20. Paralelne kristalografske ravni nalaze se na rastojanju 0,28 nm. Minimalan ugao rasejanja monohromatskog snopa X-zraka na tim ravninama je 1°. Kolika je talasna dužina X-zraka?

- a)  $3,1 \cdot 10^{-3}$  nm
- b)  $4,9 \cdot 10^{-3}$  nm
- c)  $8,2 \cdot 10^{-3}$  nm
- d)  $2,2 \cdot 10^{-3}$  nm
- e) ni jedan od gornjih rezultata nije tačan

20)

$d = 0,28 \text{ nm}$



Strnad str. 485

$2d \cos \alpha = N \lambda$       $N = 0, 1, 2$

$\cos \alpha = \frac{\Delta x}{d} \Rightarrow \Delta x = d \cos \alpha$   
 $\Delta x = 2 \Delta x$

$2\alpha + 2\theta = \pi \Rightarrow \alpha = \frac{\pi}{2} - \frac{2\theta}{2}$

$\cos\left(\frac{\pi}{2} - \frac{2\theta}{2}\right) = \cos \frac{\pi}{2} \cos \frac{2\theta}{2} + \sin \frac{\pi}{2} \sin \frac{2\theta}{2} = \sin \frac{2\theta}{2}$

$d = 0,28 \text{ nm}$

$2d \sin \frac{2\theta}{2} = N \lambda$

$N = 1$

$N=1 \quad \lambda = \frac{2d \sin(\frac{2\theta}{2})}{N} = \frac{2 \cdot 0,28}{1} \sin(0,5) \cdot \text{nm} = \underline{\underline{4,9 \cdot 10^{-3} \text{ nm}}}$

$2\theta = 0,5$      **(b)**

**(b)** je pravilan  $N=2$

5. Kolikšna je gostota magnetnega polja, če proton s kinetično energijo 4 GeV kroži po radiju 16 m. Ravnina v kateri kroži proton je pravokotna na smer magnetnega polja? Računajte relativistično!

$$W_0 = 938 \text{ MeV}$$

$$T = 4 \text{ GeV}$$

$$R = 16 \text{ m}$$

$$\frac{d(m\gamma\vec{v})}{dt} = e_0 \vec{v} \times \vec{B}, \quad |\vec{v}| = \text{const} \Rightarrow \gamma = \text{const.}$$

$$m\gamma\left(\frac{v^2}{R}\right) = e_0 v B \Rightarrow \boxed{P = m\gamma v = e_0 R B}$$

$$W^2 = (T + W_0)^2$$

$$W^2 = c^2 p^2 + W_0^2$$

$$\boxed{c^2 p^2 = 2TW_0 + T^2}$$

$$\underline{B} = \frac{P}{e_0 R} = \frac{(2TW_0 + T^2)^{1/2}}{c \cdot e_0 \cdot R} = \underline{\underline{1.01 \text{ T}}}$$

$$\frac{(2 \cdot 4 \cdot 0,938 + 16)^{1/2} \cdot 10^9}{3 \cdot 10^8 \cdot 16} = 1.01$$

7. Sinhrociklotron pospešuje protone do kinetične energije **700 MeV**. Kolikokrat moramo povečati (zmanjšati) frekvenco pospeševalnega polja, da krožijo protoni ves čas sinhrono s poljem?  $m_p c^2 = 938 \text{ MeV}$ .

$$W_k = m_p c^2 \left[ \left( 1 - \left( \frac{v}{c} \right)^2 \right)^{-1/2} - 1 \right]$$

relativistično:

$$\omega = \frac{eB}{m} \left( 1 - \left( \frac{v}{c} \right)^2 \right)^{1/2}$$

klasično:

$$eBv = m\omega v$$

$$eB = m\omega$$

$$\omega = \frac{eB}{m}$$

$$\frac{W_k}{m_p c^2} + 1 = \left( 1 - \left( \frac{v}{c} \right)^2 \right)^{-1/2}$$

$$\left( 1 - \left( \frac{v}{c} \right)^2 \right)^{1/2} = \frac{1}{1 + W_k/m_p c^2} = \underline{\underline{0.57}}$$

Električno polje zero, pospeši delec, mag. polje pa ne spremeni  $W$  kinetične

$$\boxed{E = 0}$$

$$W = W_k + m c_0^2 = m_p c_0^2$$

$$F^{\mu} = \left( e\gamma \frac{\vec{E} \cdot \vec{v}}{c_0}, e\gamma (\vec{E} + \vec{v} \times \vec{B}) \right)$$

$$W_k = m c_0^2 (\gamma - 1)$$

$$F^{\mu} = \frac{dP^{\mu}}{d\tau} = \gamma \left( \frac{1}{c_0} \frac{dW}{dt}, \frac{d\vec{P}}{dt} \right) \Leftrightarrow \begin{cases} dt = \gamma d\tau \\ P^{\mu} = \left( \frac{W}{c_0}, \vec{P} \right), \vec{P} = m\gamma \vec{v} \end{cases}$$

primanjeno (pri  $\vec{E} = 0$ ):

$$\frac{d\vec{P}}{dt} = \frac{d(m\gamma \vec{v})}{dt} = e (\vec{v} \times \vec{B})$$

$$\text{ker } \vec{v} \perp \vec{B} \text{ in } v = \text{konst} \Rightarrow \frac{d\gamma}{dt} = 0 \Rightarrow \begin{cases} \frac{d(m\gamma \vec{v})}{dt} = m\gamma \frac{d\vec{v}}{dt} \\ |\vec{v} \times \vec{B}| = vB \end{cases}$$

TOREJ!  $m\gamma e a = e v B$  in  $a = \frac{v^2}{r}$   $\omega = \frac{v}{r} \Rightarrow$

$$\Rightarrow m\gamma \frac{v^2}{r} = e v B \Rightarrow m\gamma \left( \frac{v}{r} \right) = e B \Rightarrow$$

$$\Rightarrow \omega = \frac{e \cdot B}{m\gamma} = \frac{eB}{m} \left( 1 - \left( \frac{v}{c} \right)^2 \right)^{1/2}$$