Introducción a la Física Nuclear 2024

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Campo Medio

<u>Contenido</u>:

- Campo medio y fuerza residual
- Potencial de Hartree-Fock
- Separabilidad de la función de onda
- Oscilador armónico; Woods-Saxon
- Interacción espín-momento orbital
- Núcleos mágicos

Lecturas sugeridas para Campo Medio:

- Cap. 3 libro J. **Suhonen**. From nucleons to nucleus. Springer-Verlag – Berlin. 2007
- Cap. 7 libro S. S. M. **Wong**. Introductory Nuclear Physics. Willey. 2004

Modelo de capas analítico

Aproximación de campo medio

Hamiltoniano de muchos cuerpos

$$\begin{aligned} H &= T + V \\ &= \sum_{i=1}^{A}\left[-\frac{\hbar^2}{2m_i}\right]\nabla^2_{\boldsymbol{r}_i} + \sum_{i<j=1}^{A} v(\boldsymbol{r}_i, \boldsymbol{r}_j) \end{aligned}$$

Partículas independientes **Fuerza residual**

$$H = \underbrace{\boxed{\sum_{i=1}^{A}\left[-\frac{\hbar^2}{2m_i}\right]\nabla^2_{\boldsymbol{r}_i} + \sum_{i=1}^{A} v(\boldsymbol{r}_i)}}_{H_0} + \underbrace{\boxed{\sum_{i<j=1}^{A} v(\boldsymbol{r}_i, \boldsymbol{r}_j) - \sum_{i=1}^{A} v(\boldsymbol{r}_i)}}_{V_{res}}$$

Hamiltoniano de muchos cuerpos

Modelo sin interacción

Hamiltoniano de muchos cuerpos independientes H_0

Hamiltoniano de muchos cuerpos

Modelo con interacción

$$H = H_0 + V_{res}$$

Campo medio

Hamiltoniano de muchos cuerpos independientes

$$H_0 = \sum_i^A h(\boldsymbol{r}_i)$$

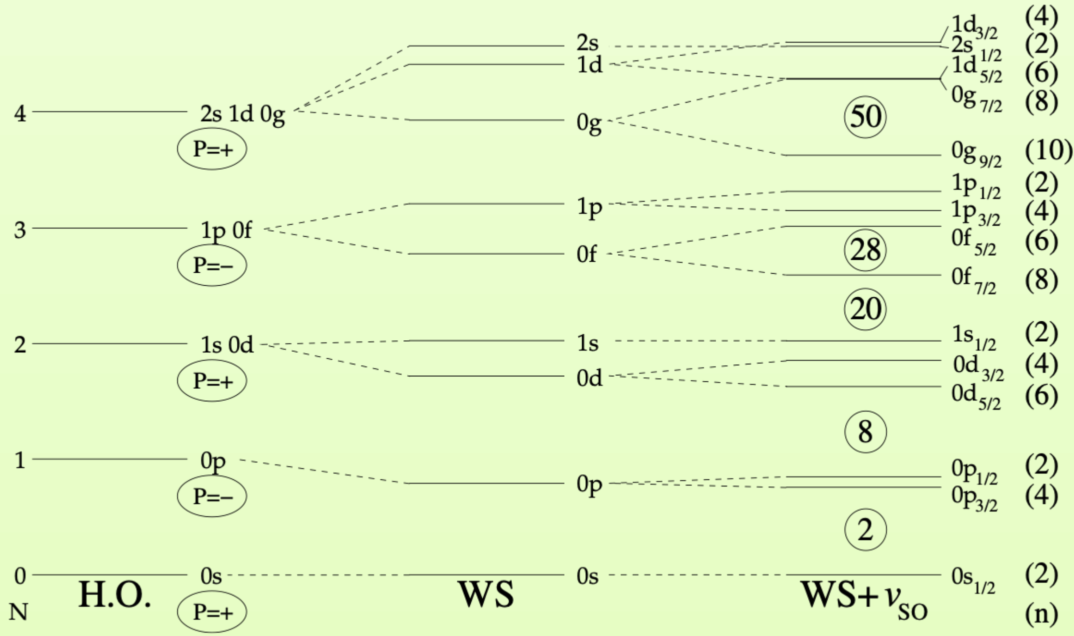
Hamiltoniano de partícula simple

$$h(\boldsymbol{r}) = \left[-\frac{\hbar^2}{2m}\right] \nabla_{\boldsymbol{r}}^2 + v(\boldsymbol{r})$$

Campo medio $v(\boldsymbol{r})$

Fuerzas: volumen + centrífuga + spin-orbit

Modelo de capas



Oscilador harmónico

Woods-Saxon

Woods-Saxon +Spin-orbit

Ecuación de Schroedinger sin spin-orbit

$$h(\boldsymbol{r}) = \frac{1}{2m}\boldsymbol{p}^2 + v(r) \qquad \boldsymbol{p}^2 = -\hbar^2\nabla^2_{\boldsymbol{r}}$$

$$h(\boldsymbol{r}) = -\frac{\hbar^2}{2m}\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right) - \frac{1}{r^2}\vec{l}^2\right] + v(r)$$

Momento angular orbital

Aquí definido adimensional!!

$$\vec{l}^2 = -\left[\frac{1}{sen\theta}\frac{\partial}{\partial\theta}\left(sen\theta\frac{\partial}{\partial\theta}\right) + \frac{1}{sen^2\theta}\frac{\partial^2}{\partial\phi^2}\right]$$

$$\begin{aligned} v(r) &= v_{nuclear}(r) + v_{coul}(r) \\ v_{coul}(r) &= \frac{Ze^2}{4\pi\epsilon_0}\begin{cases} \frac{1}{2R}\left(3 - \frac{r^2}{R^2}\right) & r \leq R \\ \frac{1}{r} & r > R \end{cases} \end{aligned}$$

Hacer las cuentas...

$$\psi_{nsm_slm_l}(r,\theta,\phi) = \frac{1}{r}R_{nl}(r)\,\chi_{sm_s}\,Y_{lm_l}(\theta,\phi)$$

Notación espectroscópica

l= 0,	1,	2,	3,	4,	5,	...	
s,	p,	d,	f,	,g	,h	...	

$$\boxed{\frac{\hbar^2}{2m}\frac{d^2R_{nl}(r)}{dr^2} + \left[\varepsilon_{nl} - v(r) - \frac{\hbar^2}{2m}\frac{l(l+1)}{r^2}\right]R_{nl}(r) = 0}$$

Funciones de onda para potencial sin spin-orbit

$$\psi_{nsm_slm_l}(r,\theta,\phi) = \frac{1}{r} R_{nl}(r)\, \chi_{sm_s}\, Y_{lm_l}(\theta,\phi)$$

$$h(\boldsymbol{r}) = -\frac{\hbar^2}{2m}\left[\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right) - \frac{1}{r^2}\bar{l}^2\right] + v(r)$$

$$\frac{\hbar^2}{2m}\frac{d^2 R_{nl}(r)}{dr^2} + \left[\varepsilon_{nl} - v(r) - \frac{\hbar^2}{2m}\frac{l(l+1)}{r^2}\right] R_{nl}(r) = 0$$

Hacer las cuentas...

En paralelo hacer
las cuentas con spin-orbit...

Solución analítica :
- W.S. con l=0
- H.O.
- Cosh

Funciones de onda para potencial sin spin-orbit

$$\psi_{nsm_slm_l}(r,\theta,\phi) = \frac{1}{r} R_{nl}(r)\, \chi_{sm_s}\, Y_{lm_l}(\theta,\phi)$$

Solución numérica

$$\frac{\hbar^2}{2m}\frac{d^2R_{nl}(r)}{dr^2} + \left[\varepsilon_{nl} - v(r) - \frac{\hbar^2}{2m}\frac{l(l+1)}{r^2}\right] R_{nl}(r) = 0$$

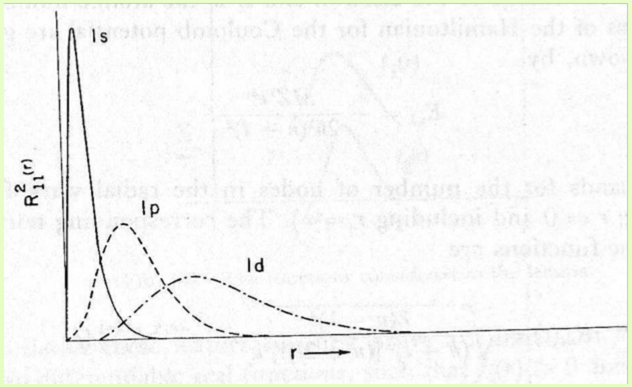
l= 0, 1, 2, 3, 4, 5, …
s, p, d, f, ,g ,h …

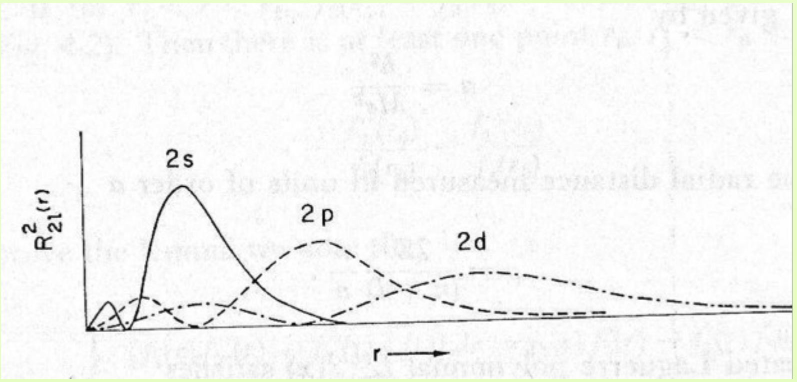
$$0s, 0p, 0d, \cdots, 1s, 1p, 1d, \cdots$$

Convención $\rightarrow n_{inicial} = 1$

$$1s, 1p, 1d, \cdots, 2s, 2p, 2d, \cdots$$

Ejemplos





Credit: A. deShalit and I. Talmi. Nuclear Shell Theory. 1963.

Construcción de campo medio autoconsistente: Hartree-Fock

(Primer acercamiento)

Función de onda de A cuerpos

$$\Psi(1,2,\cdots,A) = \mathcal{A}\psi_{\alpha_1}(r_1)\psi_{\alpha_2}(r_2)\cdots\psi_{\alpha_A}(r_A)$$

Determinante de Slatter

Principio variacional

$$\delta\langle\Psi|H|\Psi\rangle = \langle\delta\Psi|H|\Psi\rangle = 0$$

Hamiltoniano de A cuerpos

$$H = \sum_{i=1}^{A}\left[-\frac{\hbar^2}{2m_i}\right]\nabla^2_{\boldsymbol{r}_i} + \frac{1}{2}\sum_{i<j=1}^{A} v(\boldsymbol{r}_i,\boldsymbol{r}_j)$$

Hamiltoniano de un cuerpo

$$-\frac{\hbar^2}{2m}\nabla^2\psi_{\alpha_i}(\boldsymbol{r}) + \sum_{j=1}^{A}\int d\boldsymbol{r}'\,\psi^*_{\alpha_j}(\boldsymbol{r}')\,v(\boldsymbol{r},\boldsymbol{r}')\,\psi_{\alpha_j}(\boldsymbol{r}')\,\psi_{\alpha_i}(\boldsymbol{r})$$

$$-\sum_{j=1}^{A}\int d\boldsymbol{r}'\,\psi^*_{\alpha_j}(\boldsymbol{r}')\,v(\boldsymbol{r},\boldsymbol{r}')\,\psi_{\alpha_j}(\boldsymbol{r})\,\psi_{\alpha_i}(\boldsymbol{r}') = \varepsilon_{\alpha_i}\psi_{\alpha_i}(\boldsymbol{r})$$

Lo vamos a demostrar cuando hagamos segunda cuantización

Ecuación de Hartree-Fock

Hartree

$$-\frac{\hbar^2}{2m}\nabla^2\psi_{\alpha_i}(\boldsymbol{r})+\sum_{j=1}^{A}\int d\boldsymbol{r}'\,\psi^*_{\alpha_j}(\boldsymbol{r}')\,v(\boldsymbol{r},\boldsymbol{r}')\,\psi_{\alpha_j}(\boldsymbol{r}')\,\psi_{\alpha_i}(\boldsymbol{r})$$

Fock

$$-\sum_{j=1}^{A}\int d\boldsymbol{r}'\,\psi^*_{\alpha_j}(\boldsymbol{r}')\,v(\boldsymbol{r},\boldsymbol{r}')\,\psi_{\alpha_j}(\boldsymbol{r})\,\psi_{\alpha_i}(\boldsymbol{r}') = \varepsilon_{\alpha_i}\psi_{\alpha_i}(\boldsymbol{r})$$

$$\boxed{U(\boldsymbol{r},\boldsymbol{r}') = \delta(\boldsymbol{r}-\boldsymbol{r}')\sum_{j=1}^{A}\int d\boldsymbol{r}''\,v(\boldsymbol{r},\boldsymbol{r}'')\,\psi^*_{\alpha_j}(\boldsymbol{r}'')\,\psi_{\alpha_j}(\boldsymbol{r}'') - \sum_{j=1}^{A} v(\boldsymbol{r},\boldsymbol{r}')\,\psi^*_{\alpha_j}(\boldsymbol{r}')\,\psi_{\alpha_j}(\boldsymbol{r}')}$$

$$-\frac{\hbar^2}{2m}\nabla^2_{\boldsymbol{r}}\psi_{\alpha_i}(\boldsymbol{r}) + \int d\boldsymbol{r}'U(\boldsymbol{r},\boldsymbol{r}')\psi_{\alpha_i}(\boldsymbol{r}') = \varepsilon_{\alpha_i}\psi_{\alpha_i}(\boldsymbol{r})$$

Ecuación de Schroedinger no local

$$h(\boldsymbol{r})\psi(\boldsymbol{r}) = \varepsilon\psi(\boldsymbol{r})$$

Oscilador armónico

Oscilador armónico

Tres dimensiones

$$h(\boldsymbol{r})\,\varphi(\boldsymbol{r}) \quad = \quad \varepsilon\,\varphi(\boldsymbol{r})$$

$$h(\boldsymbol{r}) \quad = \quad -\frac{\hbar^2}{2m}\nabla^2 + V(r)$$

Potencial

$$V(r) \quad = \quad \frac{1}{2}m\omega^2 r^2$$

Autofunciones

$$\varphi_{nlm}(\boldsymbol{r}) \quad = \quad R_{nl}(r)\,Y_{lm}(\theta,\phi)$$

Ecuación radial

$$h(r)\,R_{nl}(r) = \varepsilon_{nl}\,R_{nl}(r)$$

$$h(r) = -\frac{\hbar^2}{2m}\left[\nabla_r^2 - \frac{l(l+1)}{r^2}\right] + \frac{1}{2}m\omega^2 r^2$$

$$R_{nl}(r) = \sqrt{\frac{2n!}{b^3\Gamma(n+l+\frac{3}{2})}}\left(\frac{r}{b}\right)^l e^{-\frac{r^2}{2b^2}}\,L_n^{l+\frac{1}{2}}(r^2/b^2)$$

$$\int_0^\infty r^2 dr R_{nl}(r) R_{n'l}(r) = \delta_{nn'}$$

Frecuencia

$$\hbar\omega \quad = \quad \frac{41}{A^{1/3}}\,MeV$$

Ancho

$$b \quad = \quad \sqrt{\frac{\hbar}{m\omega}}$$

Potencial

$$\rightarrow \frac{1}{2}m\omega^2 r^2 = \frac{1}{2}\hbar\omega\left(\frac{r}{b}\right)^2$$

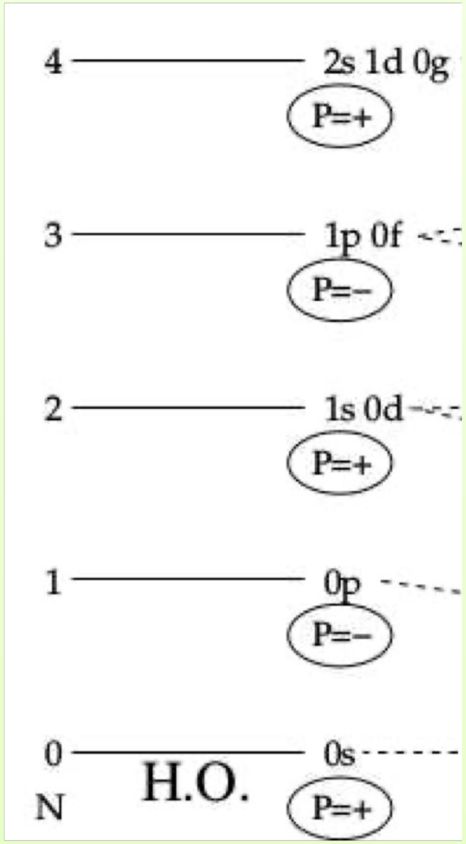
Oscilador armónico: autovalores

Autovalores

$$\varepsilon_N = \left(N + \frac{3}{2}\right)\hbar\omega \qquad N = 0, 1, 2, \cdots$$

l permitidos

$$\varepsilon_{nl} = \left(2n + l + \frac{3}{2}\right)\hbar\omega \qquad l = N, N-2, \cdots, 1, \text{ or } 0.$$



Credit: Fig. 3.5 of Ref. [22]

Máximo estados en cada capa N

$$D_N = 2\sum_{\text{allow } l}(2l+1) = 2\sum_{k=1}^{N+1} k = (N+1)(N+2)$$

Máximo estados hasta la capa N_{max}

$$D_{max} = \sum_{N=0}^{N_{max}} D_N = \frac{1}{3}(N_{max}+1)(N_{max}+2)(N_{max}+3)$$ (Acumulados)

Oscilador armónico: números mágicos

$$h(r) = -\frac{\hbar^2}{2m}\left[\nabla_r^2 - \frac{l(l+1)}{r^2}\right] + \boxed{\frac{1}{2}m\omega^2 r^2}$$

$$\hbar\omega = \frac{41}{A^{1/3}}$$

$$h(r)\,R_{nl}(r) = \varepsilon_{nl}\,R_{nl}(r)$$

$$\varepsilon_N = \left(N + \frac{3}{2}\right)\hbar\omega$$

$$N = 2n + l$$

$$N = 0, 1, 2, \cdots$$

$$D_{max} = \sum_{N=0}^{N_{max}} D_N = 2\sum_{N=0}^{N_{max}} \sum_{l=N,N-2,\ldots,1\,or\,0} (2l+1)$$

N_{max}	0	1	2	3	4	5	6	$\cdots$
D_{max}	2	8	20	40	70	112	168	$\cdots$

$$D_{max} = \sum_{N=0}^{N_{max}} D_N = \frac{1}{3}(N_{max}+1)(N_{max}+2)(N_{max}+3)$$ (Acumulados)

Oscilador armónico: números mágicos

$$h(r) = -\frac{\hbar^2}{2m}\left[\nabla_r^2 - \frac{l(l+1)}{r^2}\right] + \boxed{\frac{1}{2}m\omega^2 r^2}$$

$$h(r)\, R_{nl}(r) = \varepsilon_{nl}\, R_{nl}(r) \qquad \hbar\,\omega = \frac{41}{A^{1/3}}$$

$$\varepsilon_N = \left(N + \frac{3}{2}\right)\hbar\omega$$

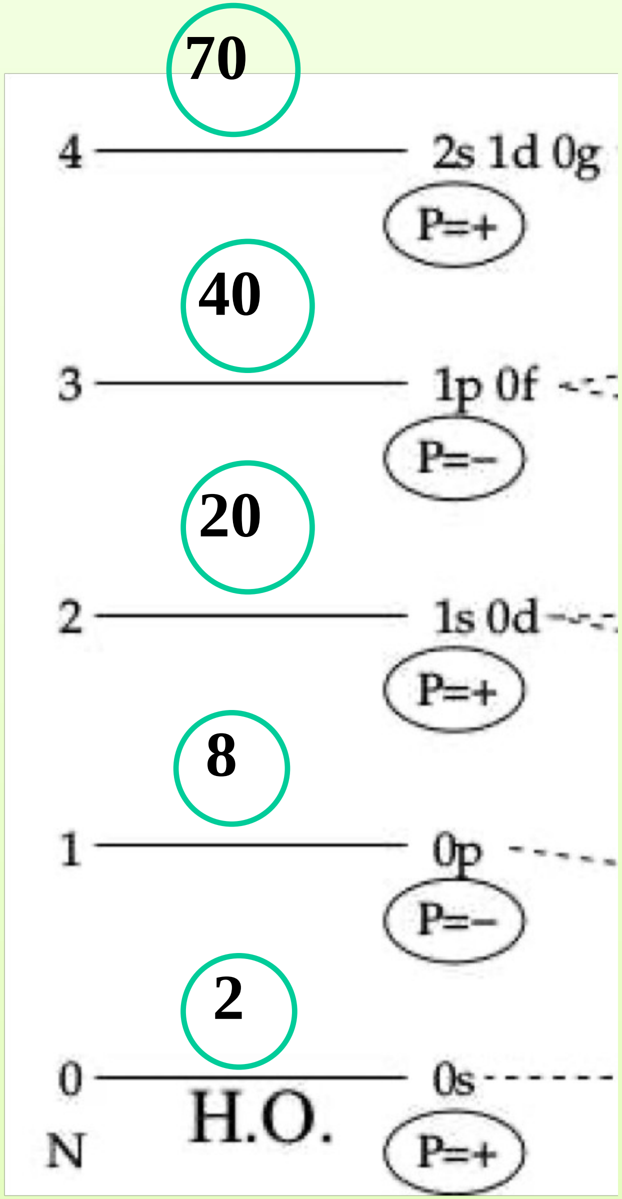
$$N = 0,1,2,\cdots$$

$$N = 2n + l$$

$$\boxed{\varepsilon_{nl} = \left(2n + l + \frac{3}{2}\right)\hbar\omega}$$

$$n = 0,1,2,\cdots$$

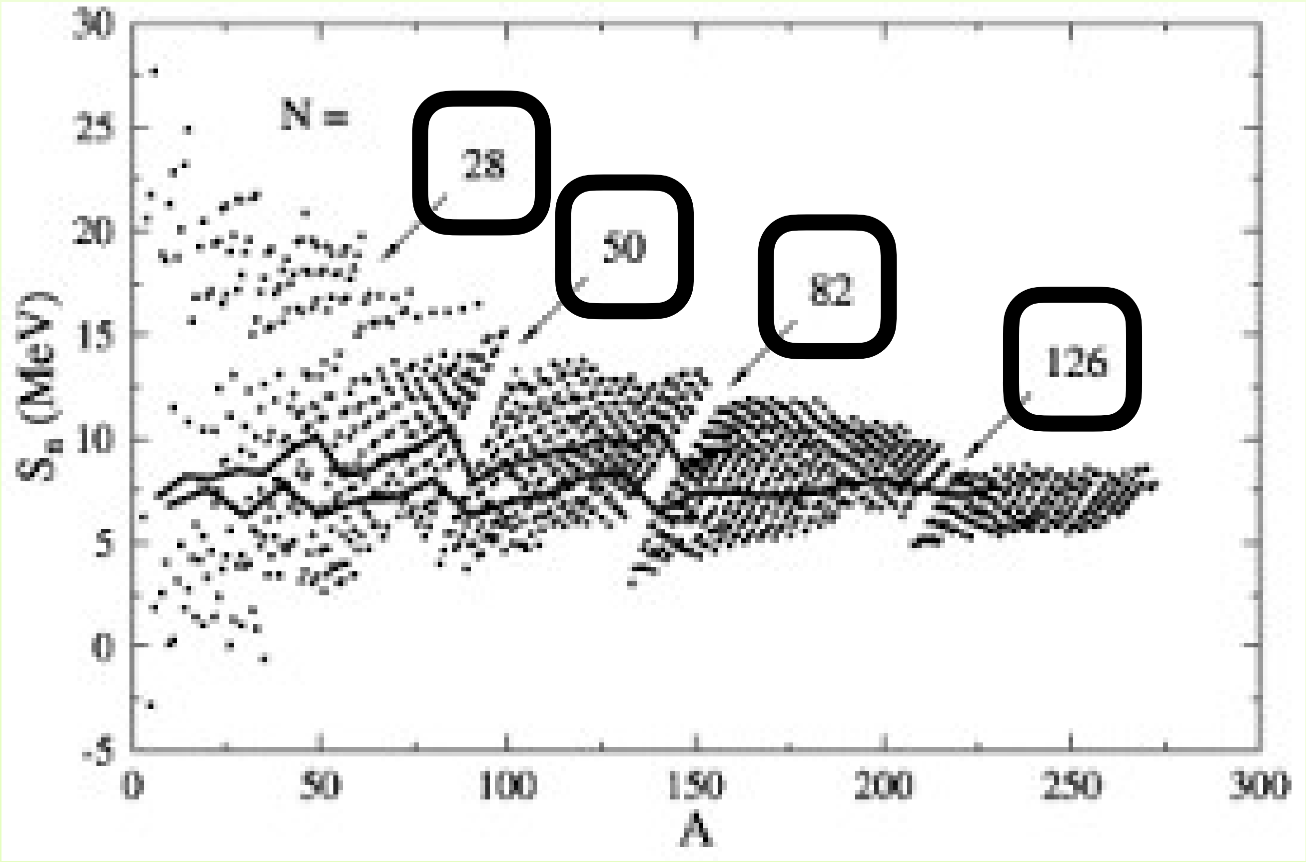
$$l = 0,1,2,\cdots$$

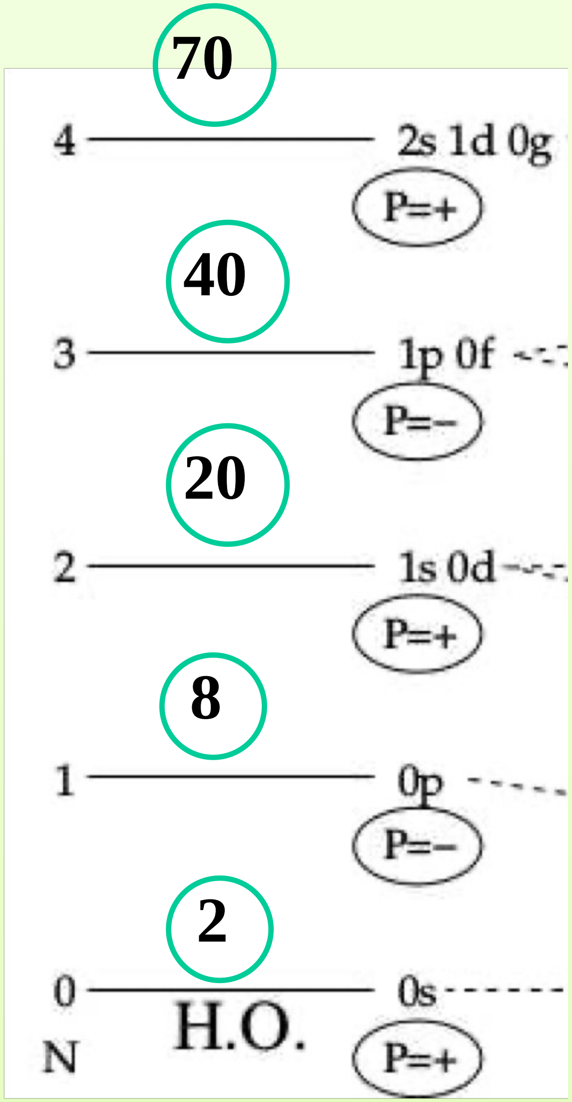


Credit: Fig. 3.5 of Ref. [22]

Oscilador armónico: números mágicos

$$h(r) = -\frac{\hbar^2}{2m}\left[\nabla_r^2 - \frac{l(l+1)}{r^2}\right] + \boxed{\frac{1}{2}m\omega^2 r^2}$$





Credit: Fig. 3.5 of Ref. [22]

Woods-Saxon

Hamiltoniano de partícula individual: Pozo finito

$$h(\boldsymbol{r}) = \left[-\frac{\hbar^2}{2m}\right] \nabla_{\boldsymbol{r}}^2 + v(\boldsymbol{r})$$

Woods-Saxon

$$\frac{\hbar^2}{2m}\frac{d^2}{dr^2}u_{nl}(r)+\left[\varepsilon_{nl}-v_{WS}(r)-\frac{\hbar^2}{2m}\frac{l(l+1)}{r^2}\right]u_{nl}(r)=0$$

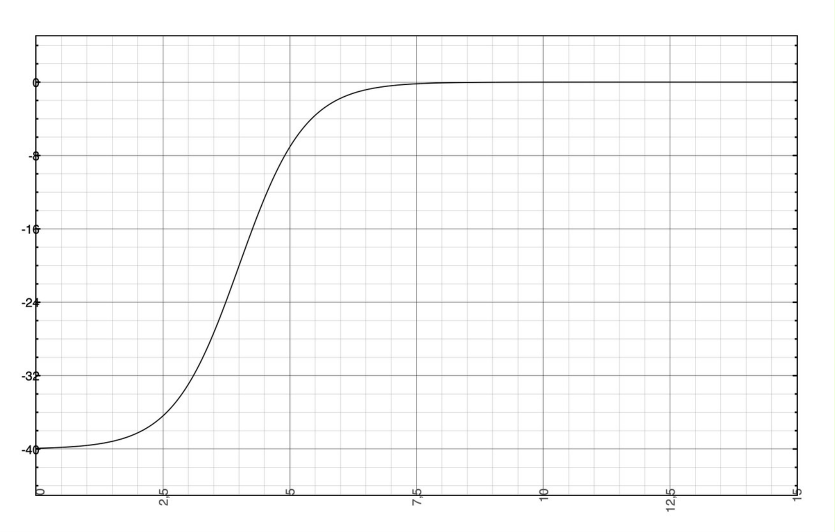
Sobre los parámetros del WS:

$$v_{WS}(r)=\frac{-V_0}{1+e^{\frac{r-R}{a}}}$$

$$R=r_0 A^{1/3}$$

(+): protón, (-):neutrón

$$V_0=\left(51\pm 33\frac{N-Z}{A}\right)MeV$$

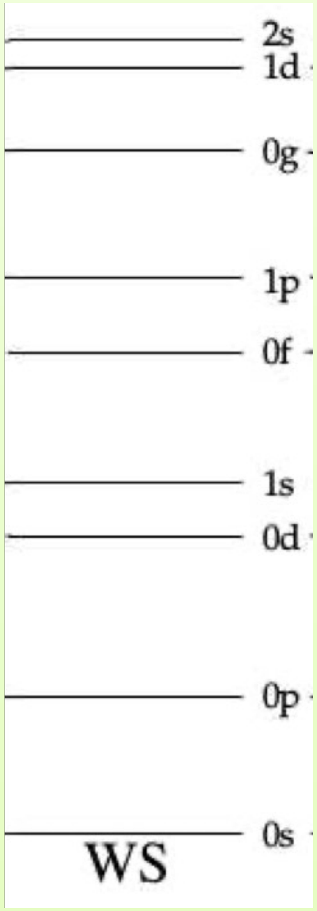


Valores para r=R,R+a

Espectro de energía del potencial de Woods-Saxon

Woods-Saxon

$$\frac{\hbar^2}{2m}\frac{d^2}{dr^2}u_{nl}(r)+\left[\varepsilon_{nl}-v_{WS}(r)-\frac{\hbar^2}{2m}\frac{l(l+1)}{r^2}\right]u_{nl}(r)=0$$



Números mágicos WS: 2, 8, 20, 40, 58

Números experimental: 2, 8, 20, 28, 50, 86

Credit: Fig. 3.5 of Ref. [22]

Comparación pozos
Infinito y finito: forma

Oscilador harmónico

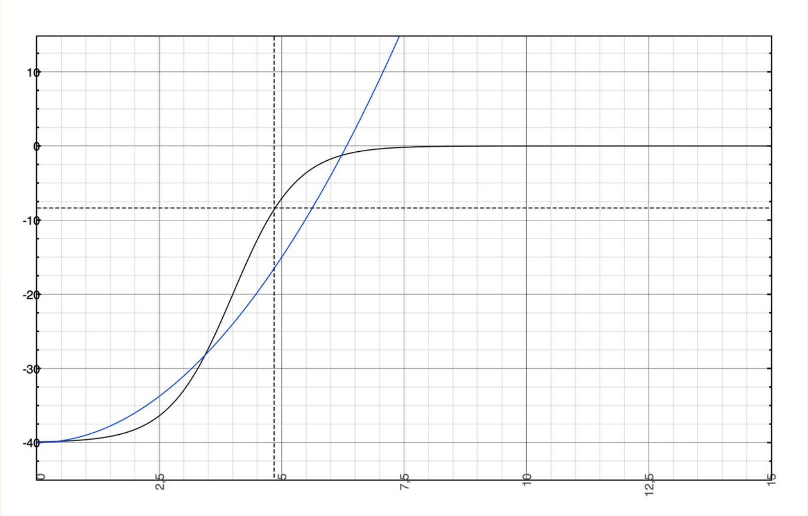
$$\frac{\hbar^2}{2m}\frac{d^2}{dr^2}u_N(r) + \left[\varepsilon_N - v_{HO}(r) - \frac{\hbar^2}{2m}\frac{l(l+1)}{r^2}\right]u_N(r) = 0$$

Woods-Saxon

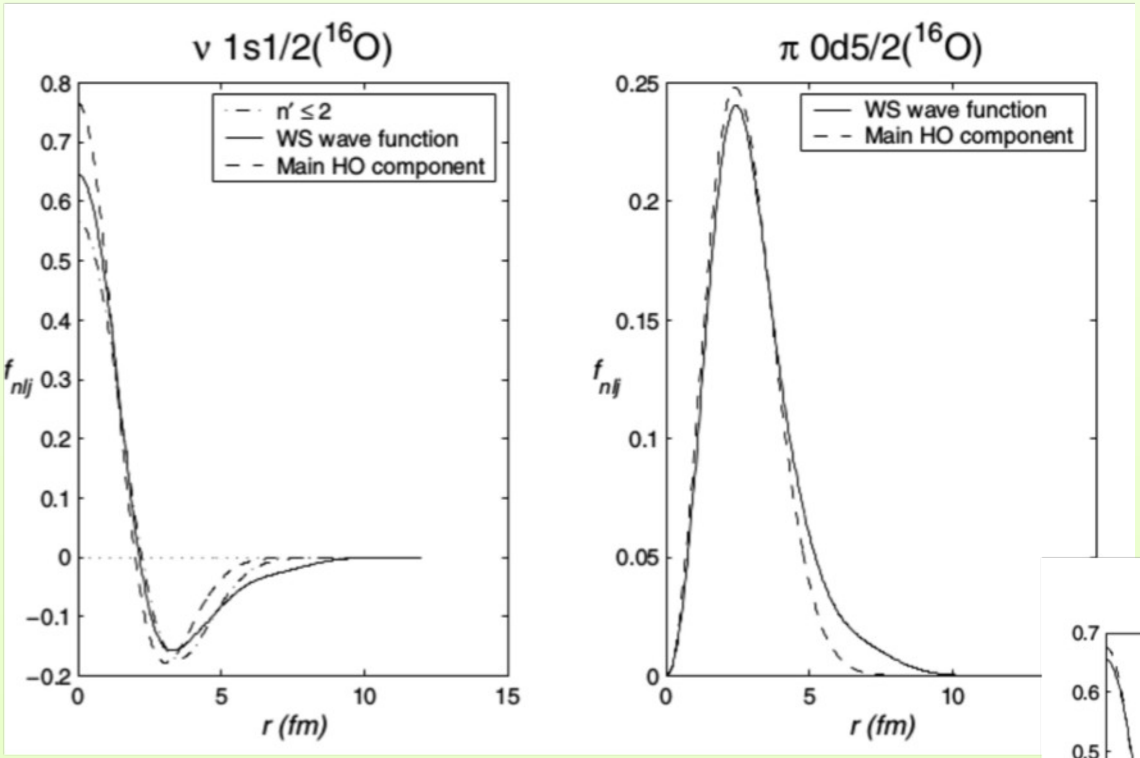
$$\frac{\hbar^2}{2m}\frac{d^2}{dr^2}u_{nl}(r) + \left[\varepsilon_{nl} - v_{WS}(r) - \frac{\hbar^2}{2m}\frac{l(l+1)}{r^2}\right]u_{nl}(r) = 0$$

$$v_{HO}(r) = \frac{1}{2}m\omega^2 r^2 \qquad \hbar\omega = \frac{41}{A^{1/3}}$$

$$v_{HO}(r) = \frac{1}{2}m\omega^2 r^2 = \frac{1}{2}m\frac{(\omega\hbar)^2}{\hbar^2}r^2 = \frac{1}{2}\frac{mc^2}{(\hbar c)^2}(\omega\hbar)^2 r^2$$



Comparación pozos
Infinito y finito: funciones de onda



Crédito: Fig. 3.4 libro Suhonen

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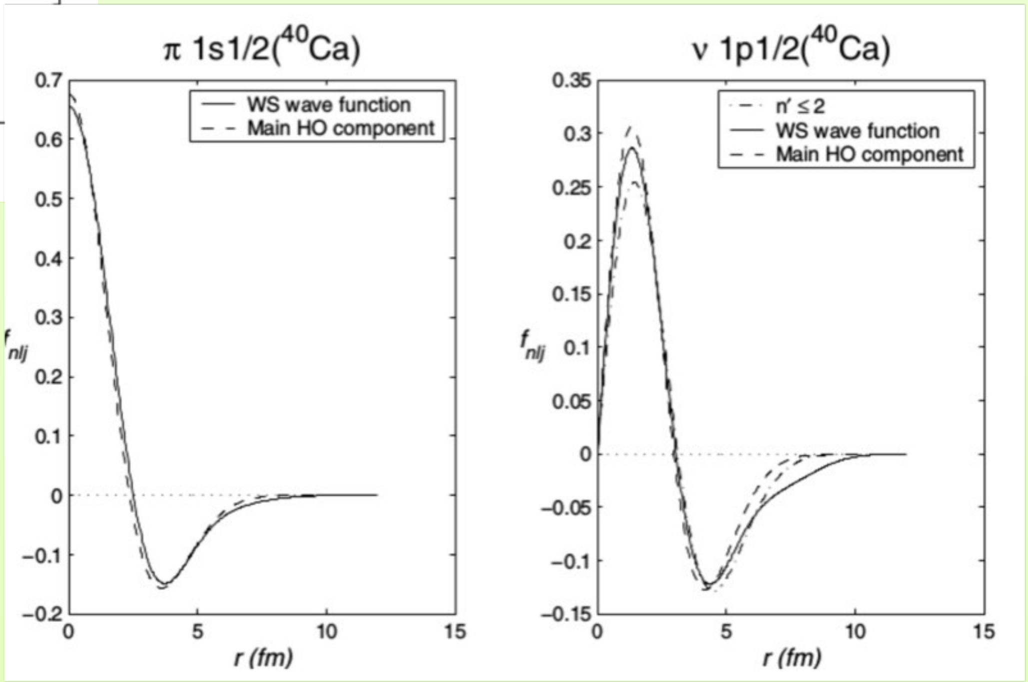


Comparación pozos Infinito y finito: espectro

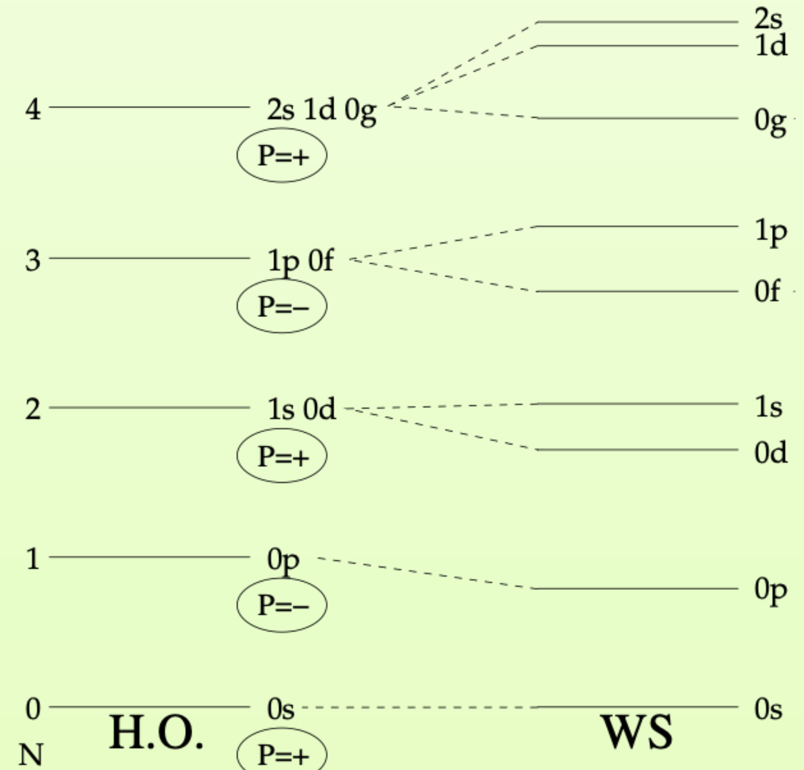
$$h(\boldsymbol{r}) \quad = \quad \left[-\frac{\hbar^2}{2m}\right] \nabla_{\boldsymbol{r}}^2 + v(\boldsymbol{r})$$

Oscilador harmónico

$$\frac{\hbar^2}{2m}\frac{d^2}{dr^2}u_N(r)+\left[\varepsilon_N - v_{HO}(r) - \frac{\hbar^2}{2m}\frac{l(l+1)}{r^2}\right]u_N(r)=0$$

Woods-Saxon

$$\frac{\hbar^2}{2m}\frac{d^2}{dr^2}u_{nl}(r)+\left[\varepsilon_{nl} - v_{WS}(r) - \frac{\hbar^2}{2m}\frac{l(l+1)}{r^2}\right]u_{nl}(r)=0$$



Credit: Fig. 3.5 of Ref. [22]

Números mágicos del o.h.: 2, 8, 20, 40, 70

Números mágicos WS: 2, 8, 20, 40, 58

Números experimental: 2, 8, 20, 28, 50, 82

Woods-Saxon con spin-orbit

Hamiltoniano de partícula individual: Woods-Saxon con spin-obit

$$h(\boldsymbol{r}) = -\frac{\hbar^2}{2m}\nabla^2 + V(r) + V_{so}(r)\,\boldsymbol{l}\cdot\boldsymbol{s}$$

$$\nabla^2 = \nabla_r^2 - \frac{\boldsymbol{l}^2/\hbar^2}{r^2} \qquad \nabla_r^2 = \frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{d}{dr}\right)$$

$$\boxed{h(\boldsymbol{r})\,\psi_{nljm}(\boldsymbol{r}) = \varepsilon\,\psi_{nljm}(\boldsymbol{r})}$$

$$\psi_{nljm}(\boldsymbol{r}) = f_{nlj}(r)\,\mathscr{Y}_{ljm}(\hat{r}) \qquad \boxed{\langle \boldsymbol{r}\,|\,\psi_{nljm}\rangle = \langle r\,|\,nlj\rangle\langle \hat{r}\,|\,lsjm\rangle}$$

Hamiltoniano de partícula individual: Woods-Saxon con spin-obit

$$h(\boldsymbol{r}) = -\frac{\hbar^2}{2m}\nabla^2 + V(r) + V_{so}(r)\,\boldsymbol{l}\cdot\boldsymbol{s}$$

$$\nabla^2 = \nabla_r^2 - \frac{\boldsymbol{l}^2/\hbar^2}{r^2}$$

$$\boldsymbol{j} = \boldsymbol{l} + \boldsymbol{s}$$

$$h(\boldsymbol{r})\,\psi_{nljm}(\boldsymbol{r}) = \varepsilon\,\psi_{nljm}(\boldsymbol{r})$$

$$\langle \boldsymbol{r}\,|\,\psi_{nljm}\rangle = \langle r\,|\,nlj\rangle\langle \hat{r}\,|\,lsjm\rangle$$

$$\boldsymbol{j}^2\,|\,lsjm\rangle = j(j+1)\,|\,lsjm\rangle$$

$$j_z\,|\,lsjm\rangle = m\,|\,lsjm\rangle$$

$$\boldsymbol{l}^2\,|\,lsjm\rangle = l(l+1)\,|\,lsjm\rangle$$

$$\boldsymbol{s}^2\,|\,lsjm\rangle = \frac{3}{4}\,|\,lsjm\rangle$$

Hamiltoniano de partícula individual: Woods-Saxon con spin-obit

$$h(r)u_{nlj}(r) = \varepsilon_{nlj}\, u_{nlj}(r)$$

$$\boldsymbol{j} = \boldsymbol{l} + \boldsymbol{s}$$

$$\boldsymbol{j}^2 \,|\, lsjm\rangle = j(j+1) \,|\, lsjm\rangle$$

$$j_z \,|\, lsjm\rangle = m \,|\, lsjm\rangle$$

$$\boldsymbol{l}^2 \,|\, lsjm\rangle = l(l+1) \,|\, lsjm\rangle$$

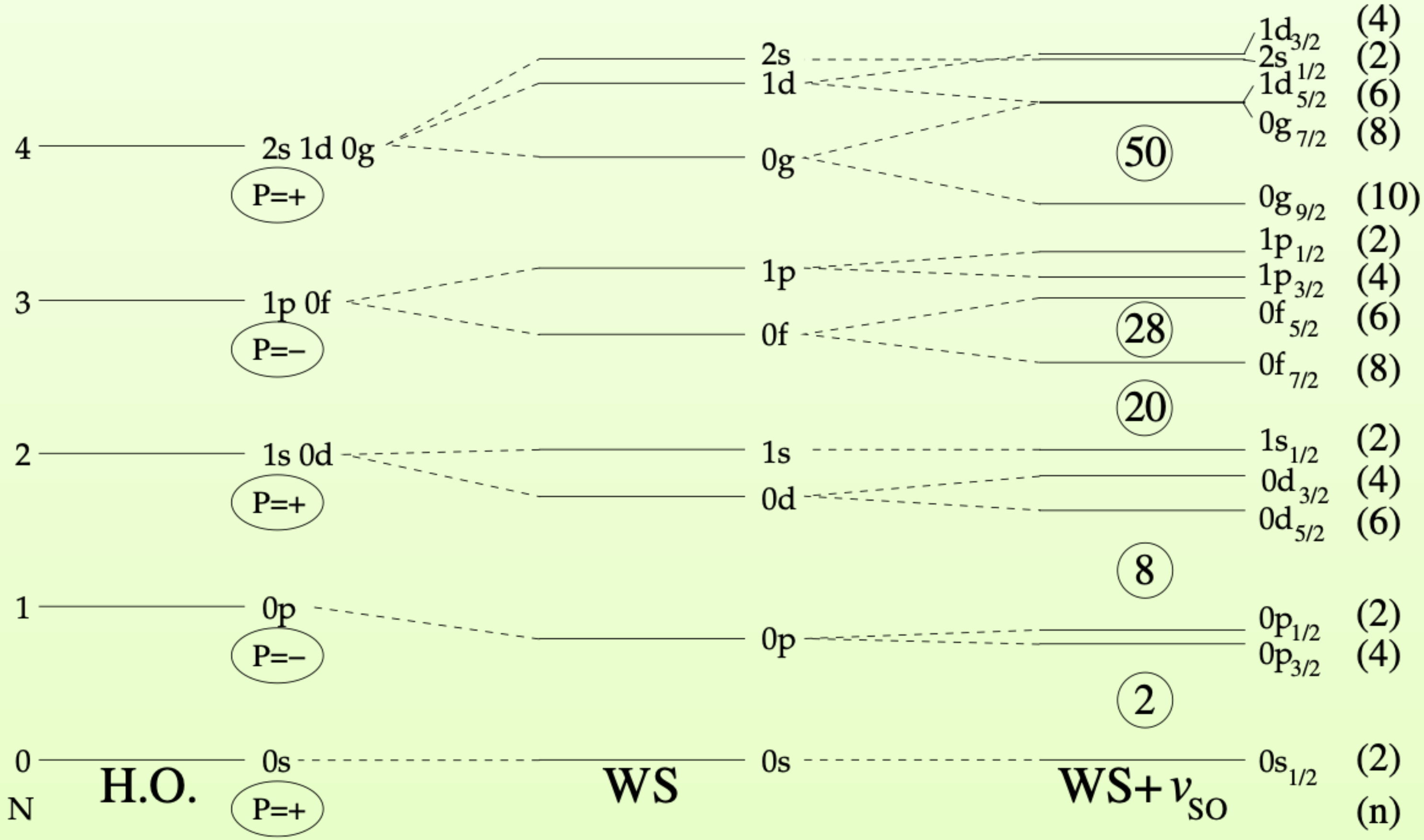
$$\boldsymbol{s}^2 \,|\, lsjm\rangle = \frac{3}{4} \,|\, lsjm\rangle$$

$$\boxed{\begin{gathered}\varepsilon_{nlj} \\ 0s_{1/2}, 0p_{3/2}, 0p_{1/2}, 0d_{5/2}, 0d_{3/2}, 1s_{1/2}, \ldots\end{gathered}}$$

$$\boxed{\frac{\hbar^2}{2m}\frac{d^2}{dr^2}u_{nlj}(r) + \left[\varepsilon_{nlj} - V(r) - \zeta_{l,j}V_{so}(r) - \frac{\hbar^2}{2m}\frac{l(l+1)}{r^2}\right] u_{nlj}(r) = 0}$$

$$\zeta_{l,j=l+1/2} = l \qquad \zeta_{l,j=l-1/2} = -(l+1)$$

Hamiltoniano de partícula individual: Woods-Saxon con spin-obit



Credit: Fig. 3.5 of Ref. [22]

Números mágicos del o.h.: **2**, **8**, **20**, 40, 70

Números mágicos WS. : **2**, **8**, **20**, 40, 58

Números WS+so. : **2**, **8**, **20**, **28**, **50**, **82, 126**

Números experimental. : 2, 8, 20, 28, 50, 82, 126

Modelo de partícula independiente

Modelo de partícula independiente

$$H = \sum_{i=1}^{A} \left[\frac{-\hbar^2}{2m_i} \right] \nabla_{r_i}^2 + \sum_{i<j=1}^{A} v(r_i, r_j) = H_0 + V$$

$$\boxed{H = H_0 + \cancel{V}}$$

$$H_0 = \sum_{i}^{A} h(r_i)$$

$$h(r)\psi_\alpha(r) = \varepsilon_\alpha \psi_\alpha(r)$$

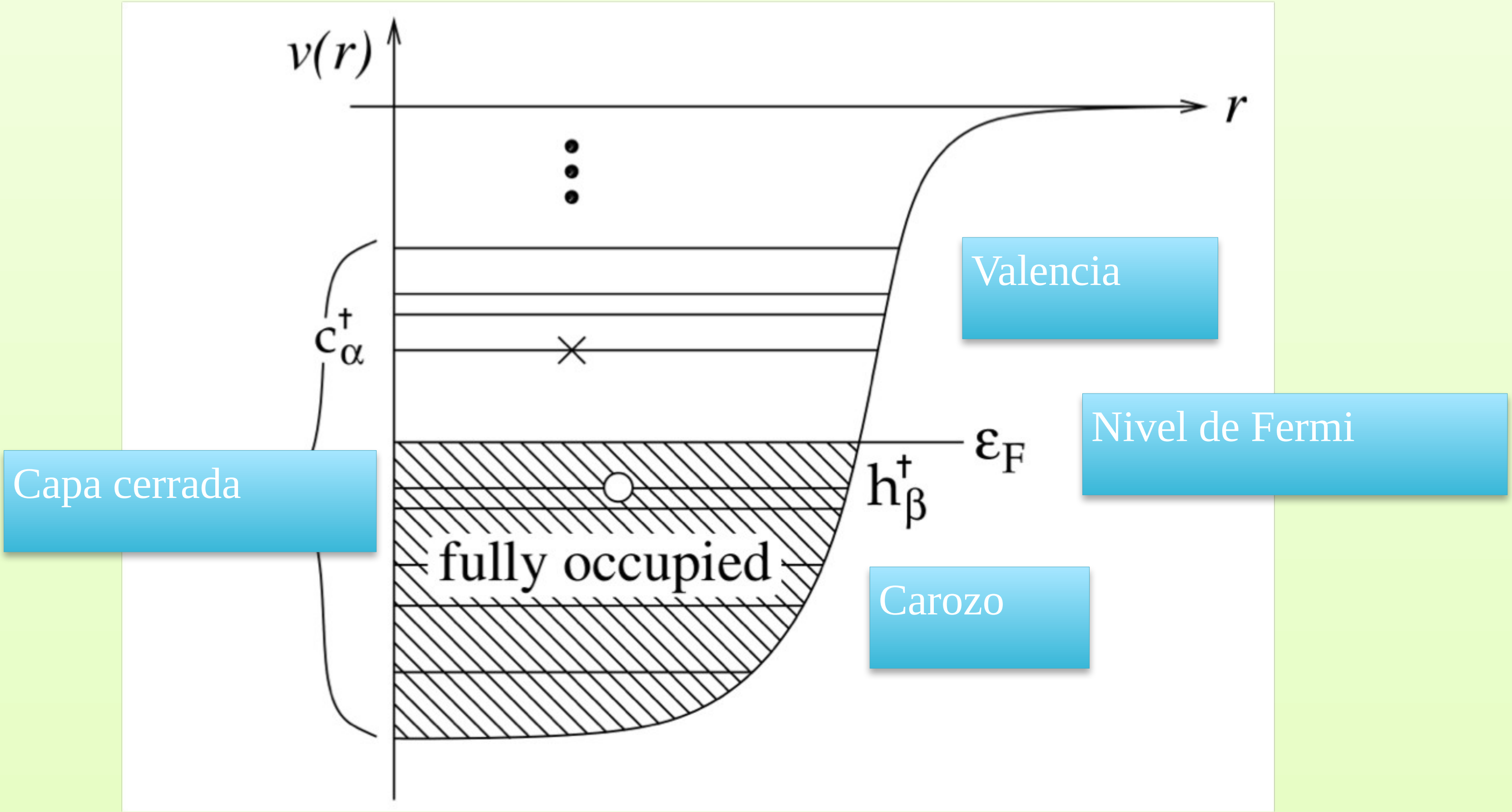
$$\Psi_0(r_1, \cdots, r_A) = \psi_{\alpha_1}(r_1) \cdots \psi_{\alpha_A}(r_A)$$

$$\boxed{E_0 = \sum_{i=1}^{A} \varepsilon_{\alpha_i}}$$

$$\boxed{H_0 \Psi_0 = E_0 \Psi_0}$$

Definición de carozo y valencia

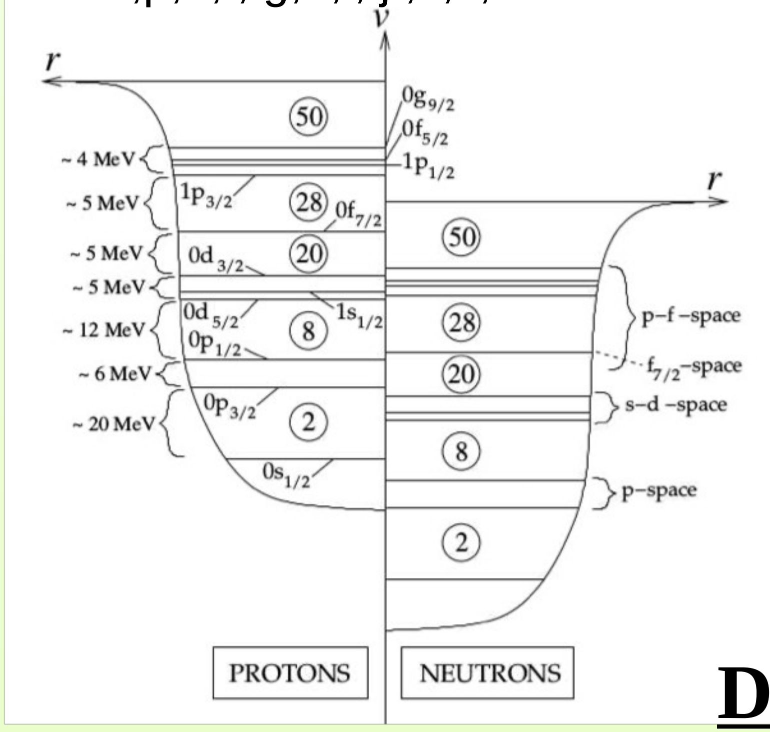
Definiciones



Crédito: Fig. 4.1 J. Suhonen. From Nucleons to Nucleus 2007

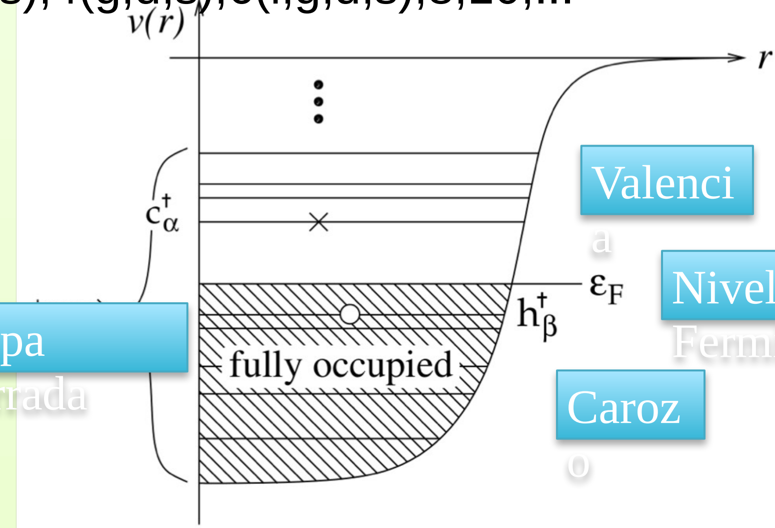
Definición de Núcleos Mágicos

L=0, 1,2,3,4,5,6,7,8
S,p,d,f, g,h,i, j ,k, l, m



Crédito: Fig. 3.3 J. Suhonen.
From Nucleons to Nucleus 2007

L=0(s),2(d,s),4(g,d,s),6(i,g,d,s),8,10,...



Valencia

Nivel de Fermi

Capa cerrada

Carozo

Crédito: Fig. 4.1 J. Suhonen. From Nucleons to Nucleus 2007

Definiciones

Núcleos semi-mágicos

Z=2,8,20,28,50, 82 $^{18}_{6}O_{8}$ $^{210}_{82}Pb_{128}$

Núcleos mágicos o Doblemente mágicos

Z=2,8,20,28,50, 82

N=2,8,20,28,50, 82, 126, 184

$^{4}_{2}He_{2}$ $^{16}_{6}O_{6}$ $^{40}_{20}Ca_{20}$ $^{208}_{82}Pb_{126}$

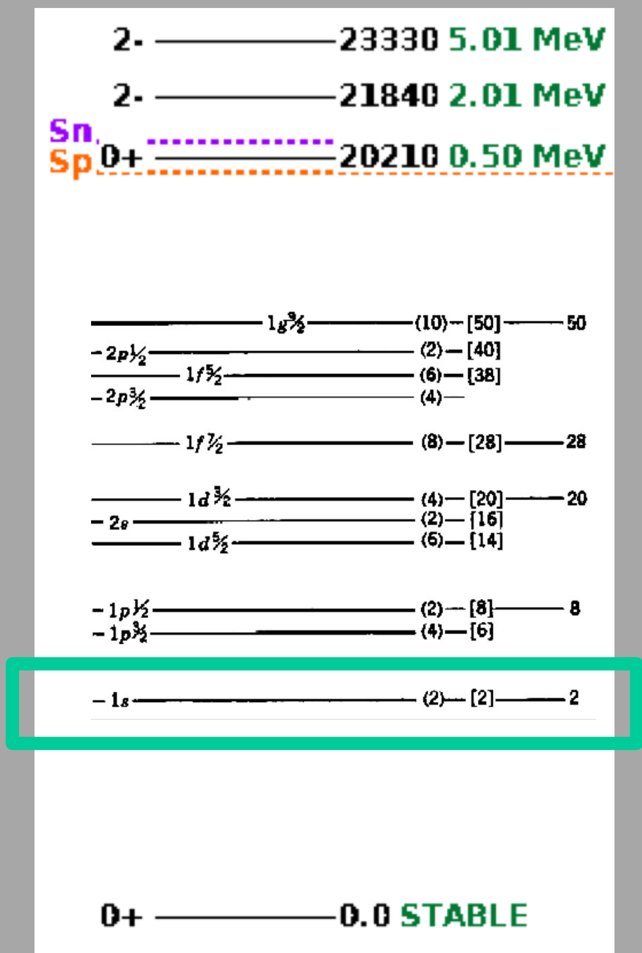
Núcleos semi-mágicos

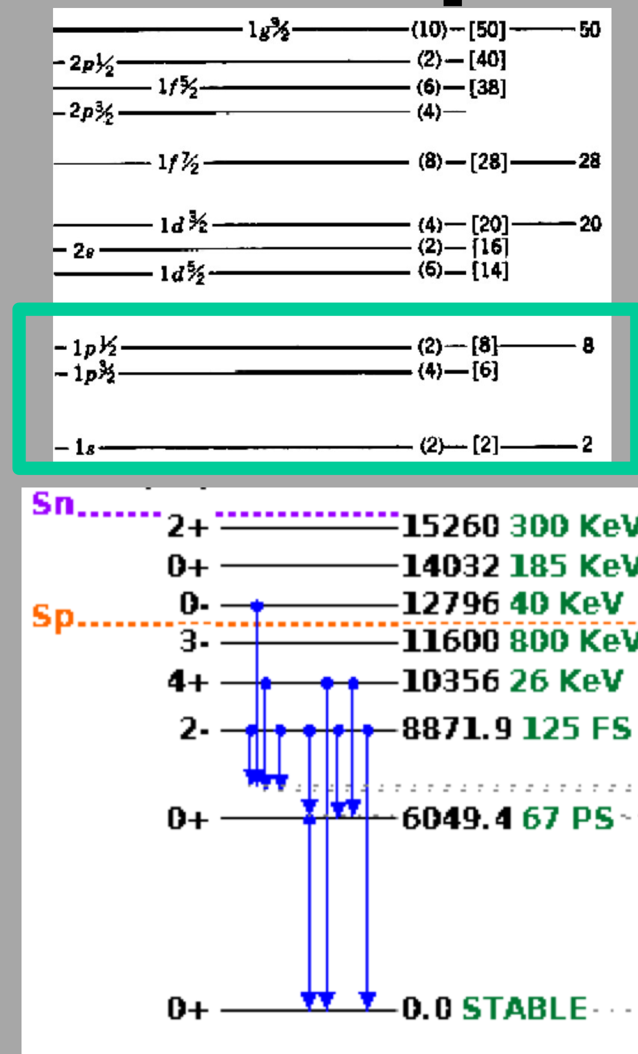
$^{210}_{84}Po_{126}$

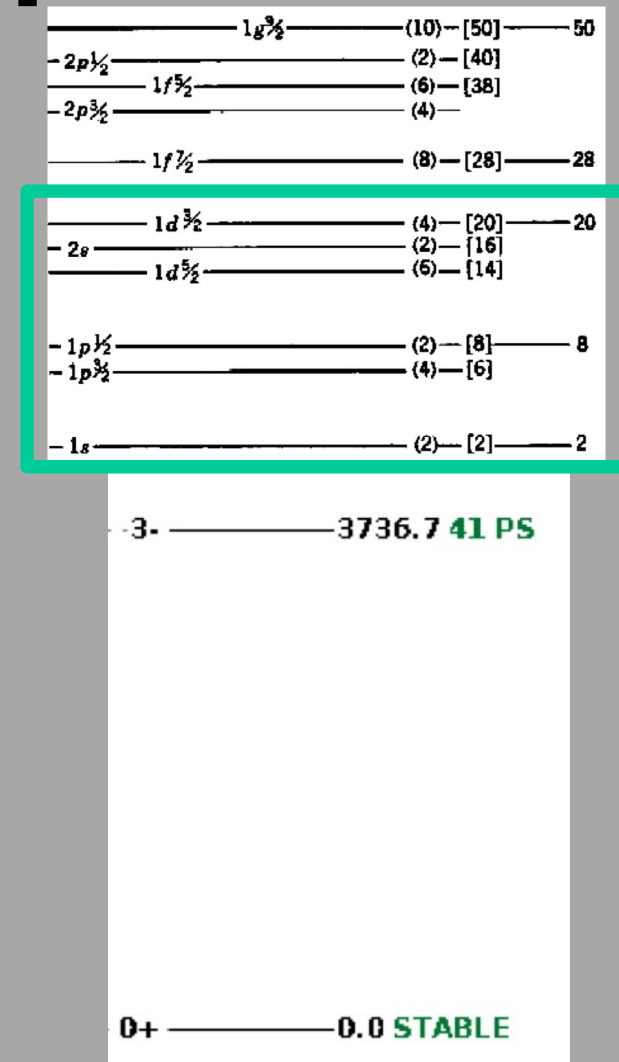
N=2,8,20,28,50, 82, 126, 184 $^{18}_{10}Ne_{8}$

Modelo de capa para capas cerradas

Estado fundamental 0+ de núcleos par-par





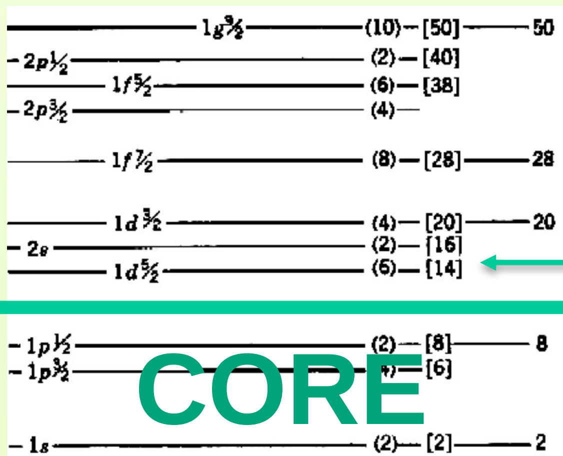


- $^{4}_{2}He_{2}$
- $^{16}_{8}O_{8}$
- $^{40}_{20}Ca_{20}$

Modelo de capa para un neutrón de valencia

Números cuánticos versus estados experimentales

Modelo: ❑$^{17}_{9}O_{8}$ ¿ $^{16}_{8}O_{8}+n$



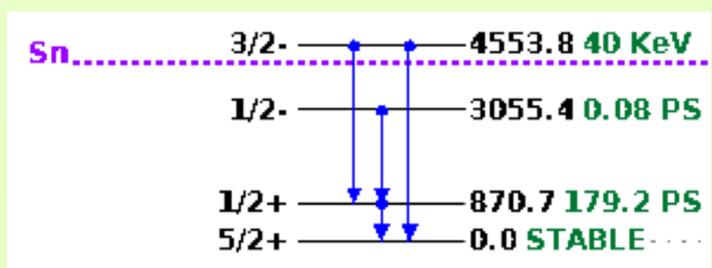
CORE

Estados excitados

$5/2^{+}$ ¿ **Estado fundamental**

0^{+} ¿¿

$\Pi =$ ¿



Experimento

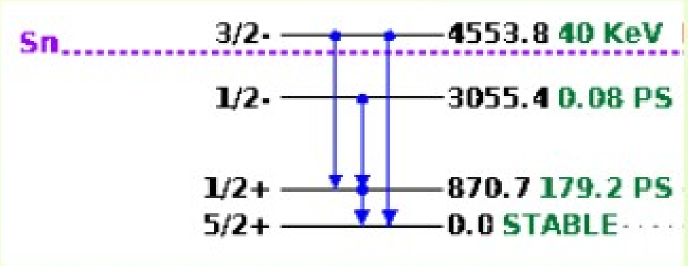
❑$^{17}_{8}O_{9}$

Energía del Estado Fundamental: neutrón de valencia

$S_n({}^{17}_{8}O_9) = B(Z = 8, N = 9) - B(Z = 8, N - 1 = 8)$

Modelo: ${}^{17}_{9}O_8 = {}^{16}_{8}O_8 + n$

$S_n = 4.143 \mathrm{MeV}$



Un neutrón en un núcleo mágico

CORE : ${}^{16}_{8}O_8$

VALENCE : n

$${}^{17}_{8}O_9$$

$$\varepsilon_{gs}({}^{17}O) = -\,S_n({}^{17}O)$$

$$\varepsilon_{gs}({}^{17}O) = \varepsilon_{d_{5/2}} = -\,4.143\,\mathrm{MeV}$$

$$\varepsilon_{s_{1/2}} = (-4.143 + 0.871)\,\mathrm{MeV}$$

PARIDAD

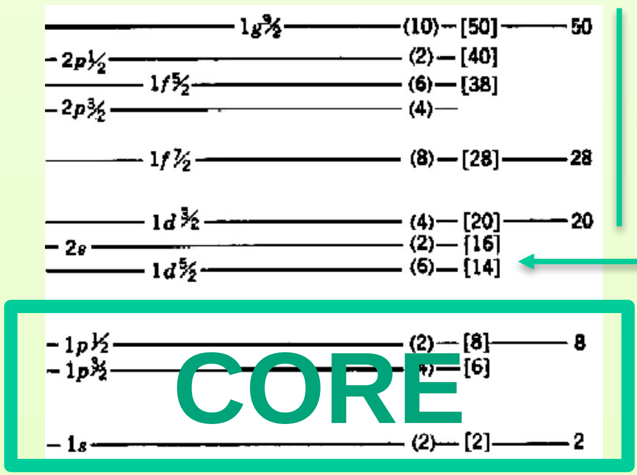
$$\Pi = (\,-\,)^l$$

Exp.	**S.M.**	**l**	π
$5/2^+$	$d_{5/2}$	2	+
$1/2^+$	$s_{1/2}$	0	+

Modelo de capa para un protón de valencia

Números cuánticos versus estados experimentales

Modelo: ❑$^{17}_{9}F_{8}$¿$^{16}_{8}O_{8}+p$

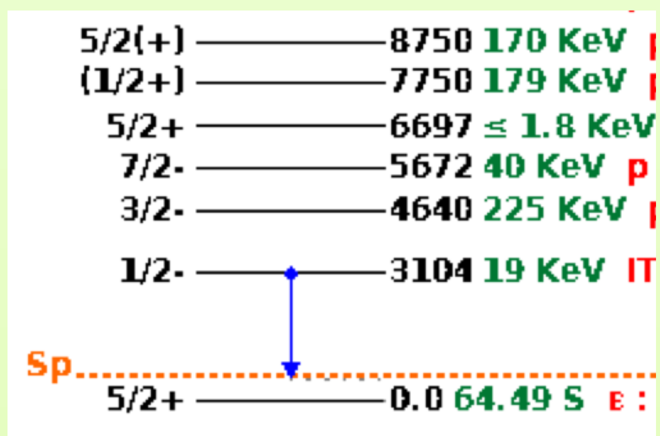


Estados excitados

$5/2^{+}$¿ Estado fundamental

0^{+}¿¿

$\Pi =$ ¿



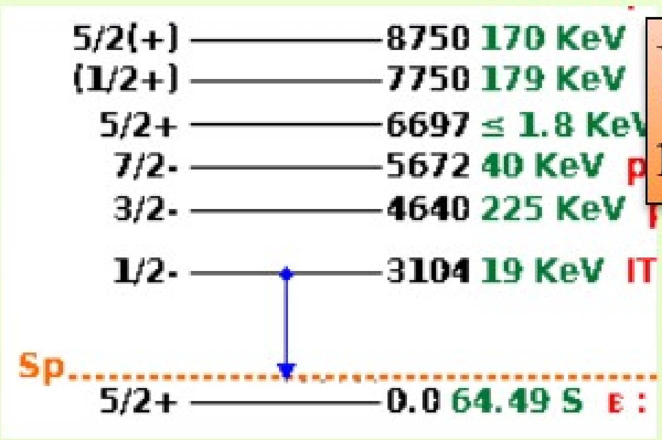
Experimento

❑$^{17}_{9}F_{8}$

Energía del Estado Fundamental: protón de valencia

$$S_p({}^{17}_{9}F_8) = B(Z = 9, N = 8) - B(Z - 1 = 8, N = 8)$$

$$S_p = 0.600\,\mathrm{MeV}$$



Un protón en un núcleo mágico

CORE : ${}^{16}_{8}O_8$

VALENCE : p

<

$${}^{17}_{9}F_8$$

$$\varepsilon_{gs}({}^{17}F) = -\,S_p({}^{17}F)$$

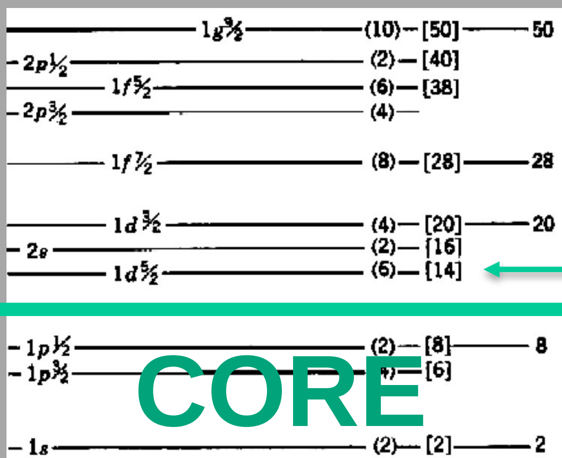
$$\varepsilon_{gs}({}^{17}F) = \varepsilon_{d_{5/2}} = -\,0.600\,\mathrm{MeV}$$

$$\varepsilon_{s_{1/2}} = (-0.600 + 7.750)\,\mathrm{MeV}\,!!!!!$$

Modelo de capa para un neutrón y un protón de valencia

Estado de núcleos impar-impar

Modelo: $\square\,{}^{18}_{9}F_{9}\text{¿}\,{}^{16}_{8}O_{8}+p+n$

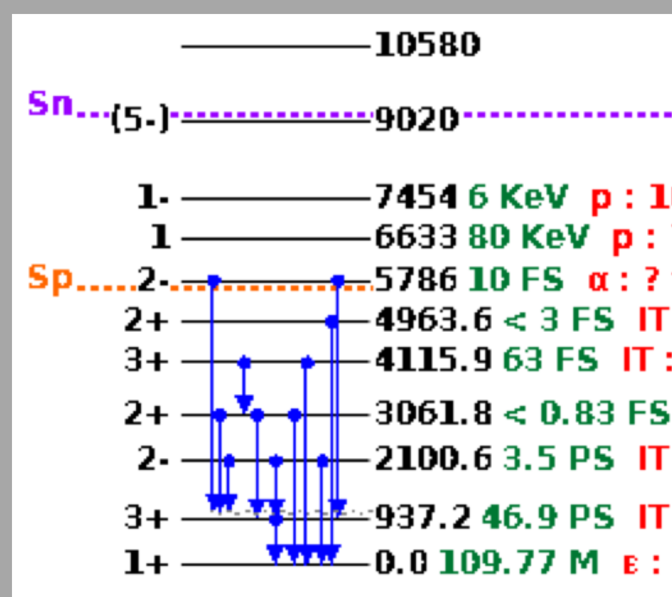


CORE

$5/2^{+}\text{¿}(p)+5/2^{+\text{¿}}(n)\rightarrow J=0,1,\cdots,6\,\text{¿}\,\text{¿}$

$0^{+\text{¿¿}}$

$\Pi=\text{¿}$



Experimento

$\square\,{}^{18}_{9}F_{9}$

Fin