

## Matrix mechanics 2

Show that for hydrogen the indicated elements of angular momentum matrices are<sup>1</sup>

$$L_1 = \begin{pmatrix} \psi_{1,0,0} & \psi_{2,1,-1} & \psi_{2,1,0} & \psi_{2,1,1} \\ \psi_{1,0,0} & 0 & 0 & 0 & \cdots \\ \psi_{2,1,-1} & 0 & 0 & \frac{\hbar}{\sqrt{2}} & 0 & \cdots \\ \psi_{2,1,0} & 0 & \frac{\hbar}{\sqrt{2}} & 0 & \frac{\hbar}{\sqrt{2}} & \cdots \\ \psi_{2,1,1} & 0 & 0 & \frac{\hbar}{\sqrt{2}} & 0 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots & \end{pmatrix}$$

$$L_2 = \begin{pmatrix} \psi_{1,0,0} & \psi_{2,1,-1} & \psi_{2,1,0} & \psi_{2,1,1} \\ \psi_{1,0,0} & 0 & 0 & 0 & \cdots \\ \psi_{2,1,-1} & 0 & 0 & \frac{i\hbar}{\sqrt{2}} & 0 & \cdots \\ \psi_{2,1,0} & 0 & -\frac{i\hbar}{\sqrt{2}} & 0 & \frac{i\hbar}{\sqrt{2}} & \cdots \\ \psi_{2,1,1} & 0 & 0 & -\frac{i\hbar}{\sqrt{2}} & 0 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots & \end{pmatrix}$$

$$L_3 = \begin{pmatrix} \psi_{1,0,0} & \psi_{2,1,-1} & \psi_{2,1,0} & \psi_{2,1,1} \\ \psi_{1,0,0} & 0 & 0 & 0 & \cdots \\ \psi_{2,1,-1} & 0 & -\hbar & 0 & 0 & \cdots \\ \psi_{2,1,0} & 0 & 0 & 0 & 0 & \cdots \\ \psi_{2,1,1} & 0 & 0 & 0 & \hbar & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots & \end{pmatrix}$$

and

$$\mathbf{L}^2 = \begin{pmatrix} \psi_{1,0,0} & \psi_{2,1,-1} & \psi_{2,1,0} & \psi_{2,1,1} \\ \psi_{1,0,0} & 0 & 0 & 0 & \cdots \\ \psi_{2,1,-1} & 0 & 2\hbar^2 & 0 & 0 & \cdots \\ \psi_{2,1,0} & 0 & 0 & 2\hbar^2 & 0 & \cdots \\ \psi_{2,1,1} & 0 & 0 & 0 & 2\hbar^2 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots & \end{pmatrix}$$

Verify

$$\mathbf{L}^2 = L_1^2 + L_2^2 + L_3^2$$

and

$$L_2 L_3 - L_3 L_2 = i\hbar L_1$$

$$L_3 L_1 - L_1 L_3 = i\hbar L_2$$

$$L_1 L_2 - L_2 L_1 = i\hbar L_3$$

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<sup>1</sup>See *Quantum Mechanics in Matrix Form* by Günter Ludyk, p. 73.

In spherical coordinates the angular momentum operators are

$$\begin{aligned}\hat{L}_1 &= i\hbar \left( \sin \phi \frac{\partial}{\partial \theta} + \cot \theta \cos \phi \frac{\partial}{\partial \phi} \right) \\ \hat{L}_2 &= i\hbar \left( -\cos \phi \frac{\partial}{\partial \theta} + \cot \theta \sin \phi \frac{\partial}{\partial \phi} \right) \\ \hat{L}_3 &= -i\hbar \frac{\partial}{\partial \phi}\end{aligned}$$

and

$$\hat{\mathbf{L}}^2 = -\hbar^2 \left( \frac{1}{\sin \theta} \frac{\partial}{\partial \theta} \left( \sin \theta \frac{\partial}{\partial \theta} \right) + \frac{1}{\sin^2 \theta} \frac{\partial^2}{\partial \phi^2} \right)$$