④ ⓐ

Here,

→ $l_2 > l_3$

→ no limits for the revolute joints so they can move and rotate about freely

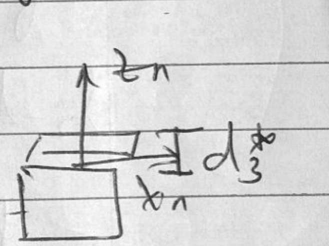
→ $0 \le d_3^* \le d_{max}$

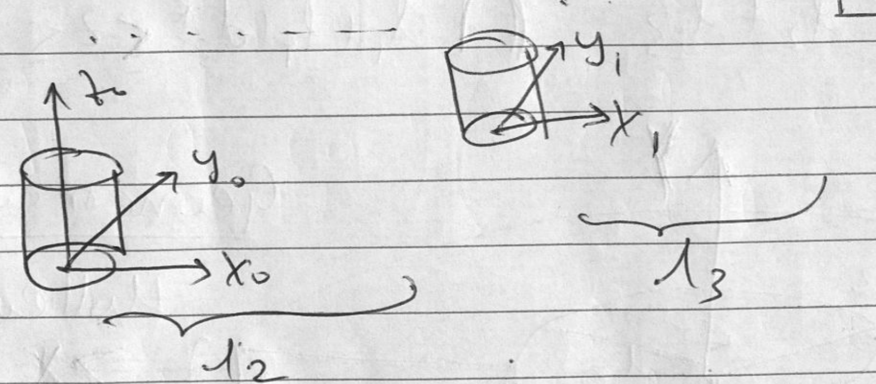
Minimum radius of the workspace would be

$$l_2 - l_3$$

and the maximum radius of the workspace would be

$$l_2 + l_3$$





Area traversed along the XY plane would be

$$l_2 - l_3 \le \sqrt{x^2 + y^2 + (z - l_1 - l_4 - d_3^*)} \le l_2 + l_3$$

Now along the Z axis we can see that since l_1 and l_4 are constant,

the only difference comes between the translation of the prismatic joints.

Hence

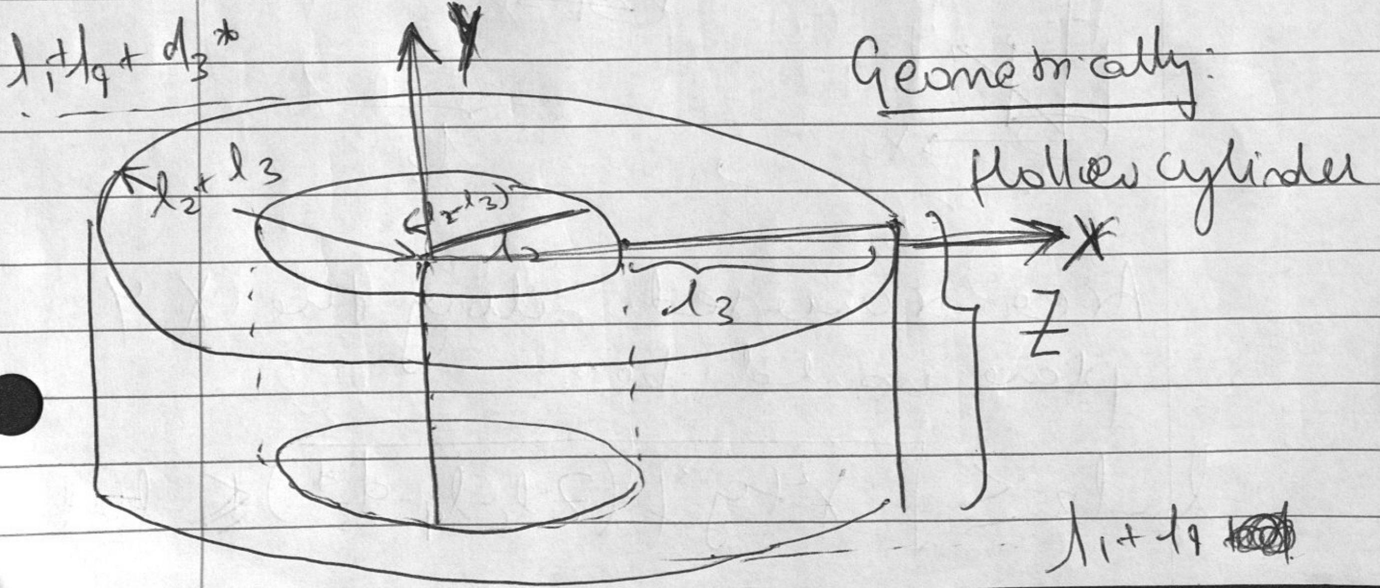
$$l_1 + l_4 + d_3^* \leq Z \leq l_1 + l_4 + d_{3max}.$$

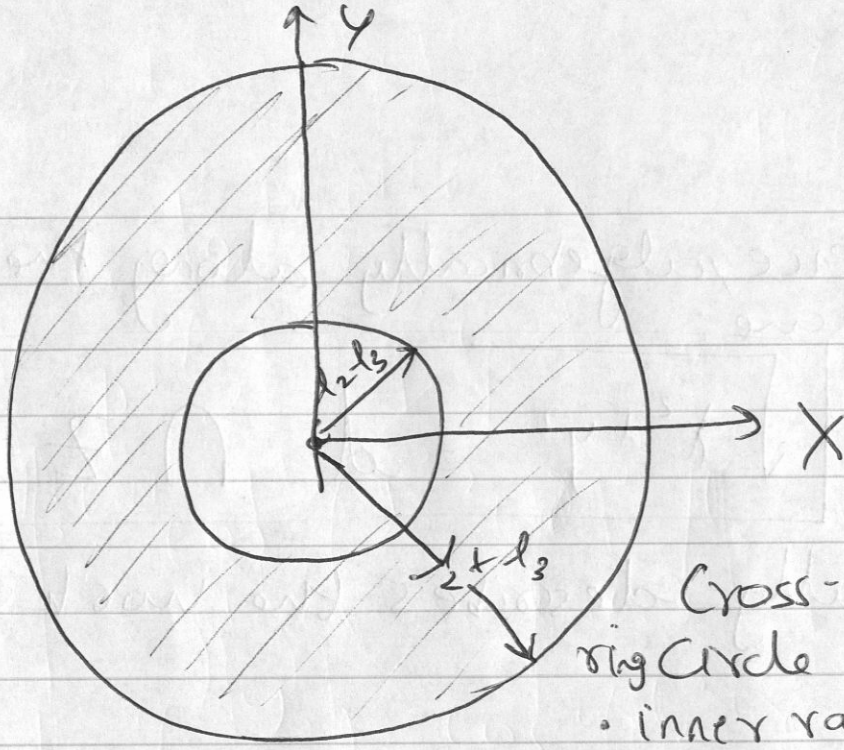
Hence final algebraic representation of the workspace is:-

$$l_2 - l_3 \leq \sqrt{X^2 + y^2 + (z - l_1 - l_4 - d_3^*)^2} \leq l_2 + l_3 \quad \bigcap \quad l_1 + l_4 + d_3^* \leq Z \leq l_1 + l_4 + d_{3max}$$

Geometrically:

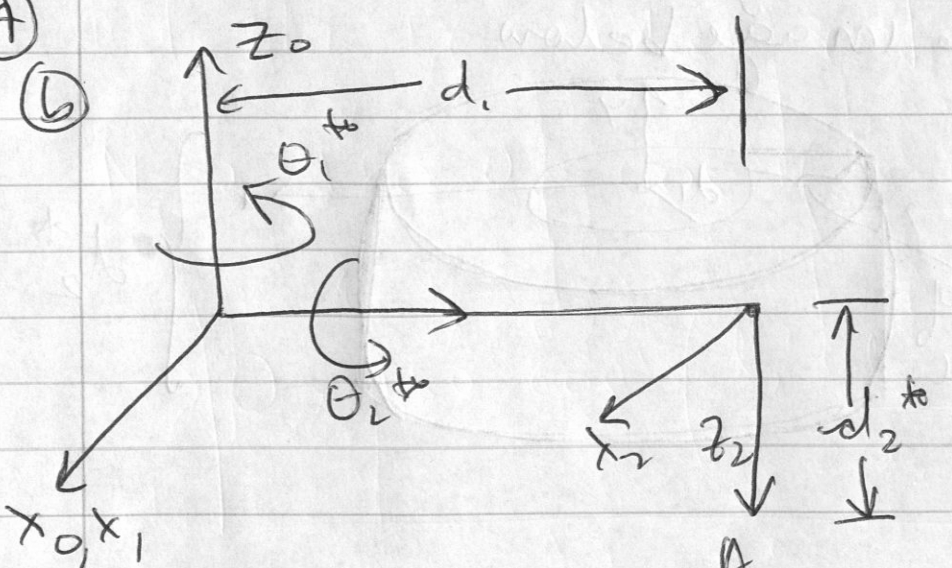
Hollow cylinder





Cross-section:
ring circle with
- inner radius $= l_2 - l_3$
- outer radius $= l_2 + l_3$

(4)
(b)



Since the reachable points are on the X–Y plane, $Z = 0$

θ_1^* can rotate full 360°.
θ_2^* can rotate full 360°.

Hence, algebrically along the X-Y plane:

$$\boxed{\sqrt{x^2+y^2} = d \cap Z = 0},$$

fully describes the workspace.

Geometrically we receive a hollow ~~spherical~~ cylinder. Better described in the image below: