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Sheet: E-001
Side: A

Task 1

$I = 10 \log_{10}\left(\frac{P}{1mW}\right)$ dBm - the reading of detector B

$P = 10^{\frac{I}{10 dBm}} \cdot mW$

$P = minim \rightarrow I = minim$; $I < 0$.

We cover the emmiter A with 2-3 layers of aluminium foil until the detector displays „- - -". Then, we try to unfoil the emmiter little by little until the detector (B) can measure the value. We repeat the experiment at least 10 times.

Number	I_{min} (dBm)
1	-107
2	-106
3	-114
4	-108
5	-125
6	-110
7	-113
8	-113
9	-120
10	~~-105~~
	-117

→ The minimum recorded:

$I_{min} = -125 dB$

$P_{min} = 10^{\frac{I_{min}}{10dBm}} \cdot mW$

$\Rightarrow P_{min} = \cancel{3.98}\ 3.16 \cdot 10^{-13}$ mW

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Task ~~2~~ 3

$$\vec{E} = \vec{E_0}(r,\varphi)\, e^{-\alpha z}\, e^{i(kz-\omega t)}$$

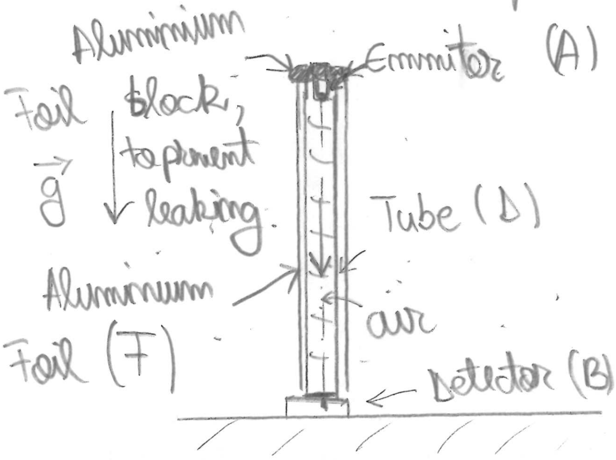
$$P \propto |\vec{E}|^2 \Rightarrow P \propto \left|E_0(r,\varphi)\, e^{-\alpha z}\, e^{i(kz-\omega t)}\right|^2$$

$$P \propto E_0^2(r,\varphi) \cdot \left|e^{i(kz-\omega t)}\right|^2 \cdot e^{-2\alpha z}$$

$$\left|e^{i(\omega t-kz)}\right|^2 = \cos^2(\omega t-kz) + \sin^2(\omega t-kz) = 1$$

$$\Rightarrow P \propto E_0^2(r,\varphi)\, e^{-2\alpha z} \qquad (1)$$

First, we place the empty tube Δ ~~horizontally~~ vertically and measure the received power (as I in dBm) in air ($\alpha = 0$).



We reconstruct the setup 10 times and measure I_{air}.

We take care to align the system correctly and hold the emmitor parallel withe the tube, which is wrapped tightly withe aluminium foil (F) and taped. The upper end is also wrapped (with the emmitor), to prevent the leaking of the signal in the wrong direction.

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# Nr.	I_{air} (dBm)
1	~~-97~~ -58
2	~~-101~~ -60
3	~~-102~~ -62
4	~~-99~~ -59
5	~~-94~~ -60
6	~~-88~~ -61
7	-57
8	-55
9	-59
10	-60

$\Rightarrow \overline{I_{air}} \simeq -59.1$ dBm.

Now, we put water into the tube, and measure the height with the stick Q (introducing the stick until we hit the bottom of the tube Δ and measuring with the ruller H the wet region). For each z (cm), we measure 10 times I(z) with the detector.

z = 8.4 cm:

#	I(z) (dBm)
1	-62
2	-63
3	-64
4	-60
5	-61
6	-63
7	-61
8	-62
9	-62
10	-63

$\Rightarrow \overline{I(z)} \simeq -62.1$ dBm.

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Side: B

$z = 17.1$ cm

#	$I(z)$ (dBm)
1	-66
2	-65
3	-70
4	-62
5	-62
6	-63
7	-65
8	-66
9	-64
10	-65

$\Rightarrow \overline{I(z)} = -64.8$ dBm

$z = 25.0$ cm

#	$I(z)$ (dBm)
1	-68
2	-72
3	-71
4	-65
5	-66
6	-67
7	-68
8	-67
9	-71
10	-66

$\Rightarrow \overline{I(z)} = -68.1$ dBm

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$z = 33.7\,cm$

#	$I(z)$
1	71
2	75
3	73
4	70
5	69
6	69
7	68
8	72
9	73
10	70

$\Rightarrow \overline{I(z)} = -71.0\,dBm.$

$z = 42.5\,cm$

#	$I(z)$
1	-73
2	-69
3	-74
4	-74
5	-73
6	-72
7	-75
8	-74
9	-74
10	-73

$\Rightarrow \overline{I(z)} = -73.1\,dBm$

$$(1) \Rightarrow \left.\begin{array}{l} P = P_0 e^{-2\alpha z} \\ P = 10^{\frac{I}{10dBm}} \cdot mW \end{array}\right\} \Rightarrow 10^{\frac{I(z)}{10dBm}} = 10^{\frac{I_{air}}{10dBm}} \cdot e^{-2\alpha z}$$

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$$\lg\left(10^{\frac{I(z)}{10dBm}}\right) = \lg\left(10^{\frac{I_{air}}{10dBm}}\right) - 2\alpha z$$

$$\frac{I(z)}{10dBm}\lg 10 = \frac{I_{air}}{10dBm}\lg 10 - 2\alpha z$$

$$\Rightarrow \frac{I(z)}{10dBm} = \frac{I_{air}}{10dBm} - \frac{2\alpha}{\lg 10}\cdot z$$

We plot $\frac{I(z)}{10dBm} = a + bz$ and find $b = \frac{2\alpha}{\lg 10}$

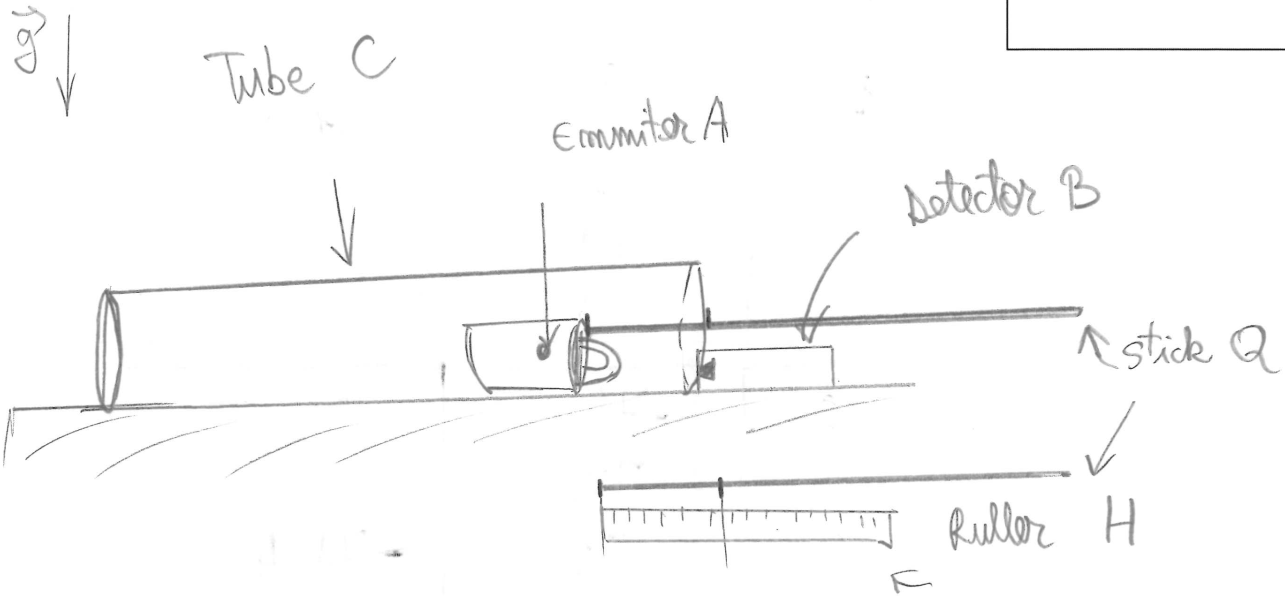
$\Rightarrow \alpha = \frac{\lg 10}{2}\cdot b$ (plot E-016 A)

$b = \frac{-1.25}{42.5-2.5}\ cm^{-1}$; $b \simeq 3.13\cdot 10^{-2}\ cm^{-1}$

$\Rightarrow \alpha = 3.60\cdot 10^{-4}\ m^{-1}$

Task 4a

We place the tube C horizontally and the detector at one of its ends. We place the emmiter right next to the detector and push the emmiter inside the tube with the stick Q a desired lenght (measured with the ruller on the stick and marked on the stick). We collect 5 datas for each z and find $P(z)$ from $I(z) = 10\log_{10}\left(\frac{P}{1mW}\right)$ dBm.



$$z = z_{ruller} + \Delta z$$
$$\Delta z = 6\,mm.$$

z (cm)	$I(z)$ (dBm)	$\bar{I}(z)$ (dBm)
2	−36 −35 −35 −36 −36	−35.6
3	−45 −45 −44 −46 −45	−45.0
4	−51 −51 −51 −52 −50	−51.0

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z (cm)	I(z) (dBm)	Ī(z) (dBm)
5	-61 -61 -61 -61 -61	-61.0
6	-71 -72 -72 -71 -71	-71.4
7	-81 -82 -81 -81 -82	-81.4
8	-90 -91 -90 -90 -89	-90.0
9.	-97 -97 -98 -97 -97	-97.2
10	-106 -105 -106 -105 -105	-105.4.

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z (cm)	$I(z)$ (dBm)	$\bar{I}(z)$ (dBm)
11	-114	-114.2
	-114	
	-115	
	-114	
	-114	

$$\bar{I}(z) = I_0 - \mu_0 z$$

Let's plot $\bar{I}(z)$ (z) on E-016 B.

From plot $\rightarrow$ $-\tan\phi = \mu_0 = \frac{79 \text{ dBm}}{9 \text{ cm}}$; $\mu \simeq 8.78$ dBm/cm

$$\cancel{P(z) = 10^{\frac{I_0 - \mu_0 z}{10 \text{ dBm}}} \text{ mW}}$$

$$\cancel{P(z) = P_0 \cdot 10^{-\frac{\mu_0}{10 \text{ W}} z} \text{ mW}}$$

$$\cancel{P(z) = P_0 \, 10^{-\mu z} \text{ mW}}$$

$$\cancel{\mu \simeq 8.78 \frac{\text{dBm}}{\text{cm} \cdot \text{mW}}}$$

$$P(z) = 10^{\frac{I_0 - \mu_0 z}{10 \text{ dBm}}} \text{ mW}.$$

$$P(z) = P_0 \, 10^{-\frac{\mu_0}{10 \text{ dBm}} z} \cancel{\text{mW}}$$

$$P(z) = P_0 \, 10^{-\mu z} \cancel{\text{mW}}$$

$$\mu \simeq 0.88 \text{ cm}^{-1}$$

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Side: B

Task 4b

We repeat the measurements from 4a using different tubes.

$d_2 = 46\,mm$:

z (cm)	$I(z)$ (dBm)
2	-33
3	-40
4	-48
5	-55
6	-63
7	-71
8	-81
9	-88
10	-96
11	-105

Plot E-017 A:

$$I = I_0 - \mu_{20} \cdot z$$

$$\Rightarrow \mu_{20} = \frac{65\,dBm}{8\,cm} \approx 8.13\,dBm/cm.$$

$$\Rightarrow \mu_2 \approx 0.81\,cm^{-1} \quad ; P_2(z) = P_0 e^{-\mu_2 z}$$

$d_3 = 59\,mm$:

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z (cm)	$I(z)$ (dBm)
2	-33
3	-41
4	-45
5	-50
6	-57
7	-63
8	-69
9	~~-76~~ -77
10	-84
11	-91

$$I = I_0 - \mu_{30} z$$

$$P_3(z) = P_0 e^{-\mu_3 z}$$

Plot E-017B:

$$\mu_{30} = \frac{62 \text{ dBm}}{9 \text{ cm}} = 6.89 \text{ dBm/cm}$$

$$\mu_3 \approx 0.69 \text{ cm}^{-1}$$

$d_4 = 100$ mm :

z (cm)	$I(z)$ (dBm)
2	~~-27~~ -33
3	-36
4	-39
5	-43
6	-47
7	-50
8	-53
9	-56
10	-59
11	-63

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$I = I_0 - \mu_{40} z$

$P_z = P_0 e^{-\mu_4 z}$

Plot E-018 A: $\mu_{40} = \dfrac{30\,dBm}{9\,cm} \approx 3.33\ dBm/cm.$

$$\mu_4 \approx 0.33\ cm^{-1}$$

d (cm)	$\mu(d)$ (cm^{-1})
4.1	0.88
4.6	0.81
5.9	0.69
10.0	0.33

$\ln d$	$\ln \mu$
1.41	-0.13
1.53	-0.21
1.77	-0.37
2.30	-1.17

Let it be ~~Fi~~ $\mu(d) = \alpha d^{\beta}$

$$\ln \mu = \ln \alpha + \beta \ln d.$$

Plot E-018B: Linear regression $\Rightarrow \beta \approx -1.5$; $\ln \alpha \approx 2.00$

$\Rightarrow \mu(d) = \alpha d^{-3/2}$; $\alpha \approx 7.3\ cm^{1/2}$

$\Rightarrow \mu(d) = 7.3\, d^{-3/2}$, μ in cm and d in cm.

Or, $\mu(d) = 7.3\ cm^{1/2}\, d^{-3/2}$

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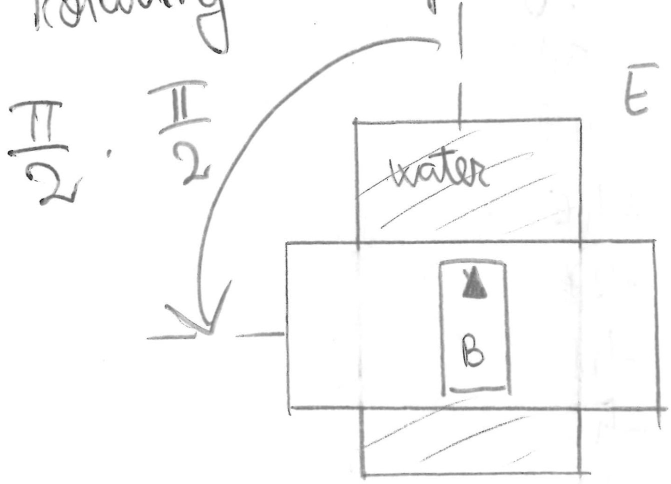
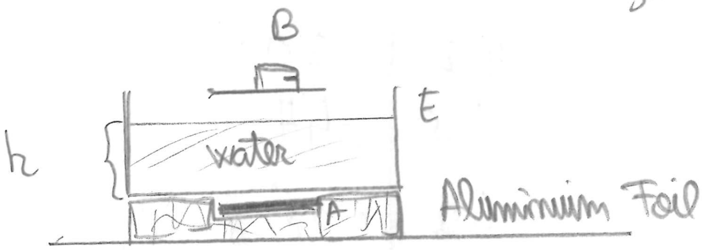
Task 2

We construct the setup from fig 2 and place the detector on the top of the box E, rotating the superior/ detachable) wall of the box by

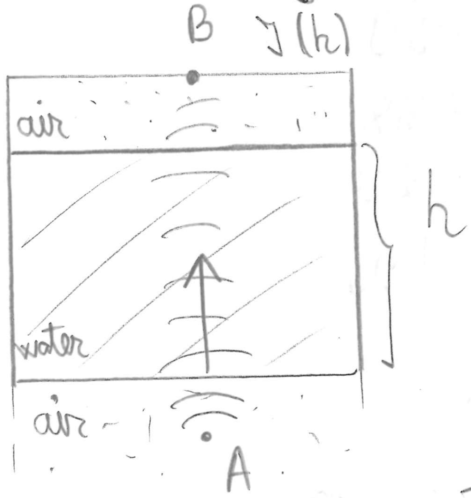


top view

Side view



h - height of water



We fill the box with water little by little and measure I(h).

We can measure h with the stick Q and the ruller H, or just with ruller H.

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h (cm)	Y(h) dBm
~~0.0~~	~~-52~~
0.8	-37
1.2	-46
1.4	-49
1.5	-50
1.6	-51
2.0	-49
2.5	-46
2.9	-37
3.1	-41
3.2	-45
3.4	-47
3.6	-51
3.8	-50
4.0	-47
4.2	-46
4.4	-43
4.6	-42
4.8	-39
4.9	-38
5.0	-39
5.1	-42

See Y(h) in plot E-019 A

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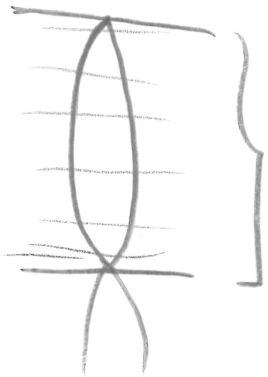
we notice the periodic $I(h)$ with

$\Delta h \approx 2\,cm$.

$$\Delta h = \frac{\lambda_w}{2} \Rightarrow \lambda_w = 2\Delta h, \quad \lambda_w = 4\,cm$$



$\Delta h = \frac{\lambda}{2}$

Task 5

$$\lambda_{water} = n\,\lambda_{air}$$

$$n = \frac{\lambda_{water}}{\lambda_{air}} \; ; \quad \lambda_{air} \approx 3\,cm$$

$$n = 1.33$$

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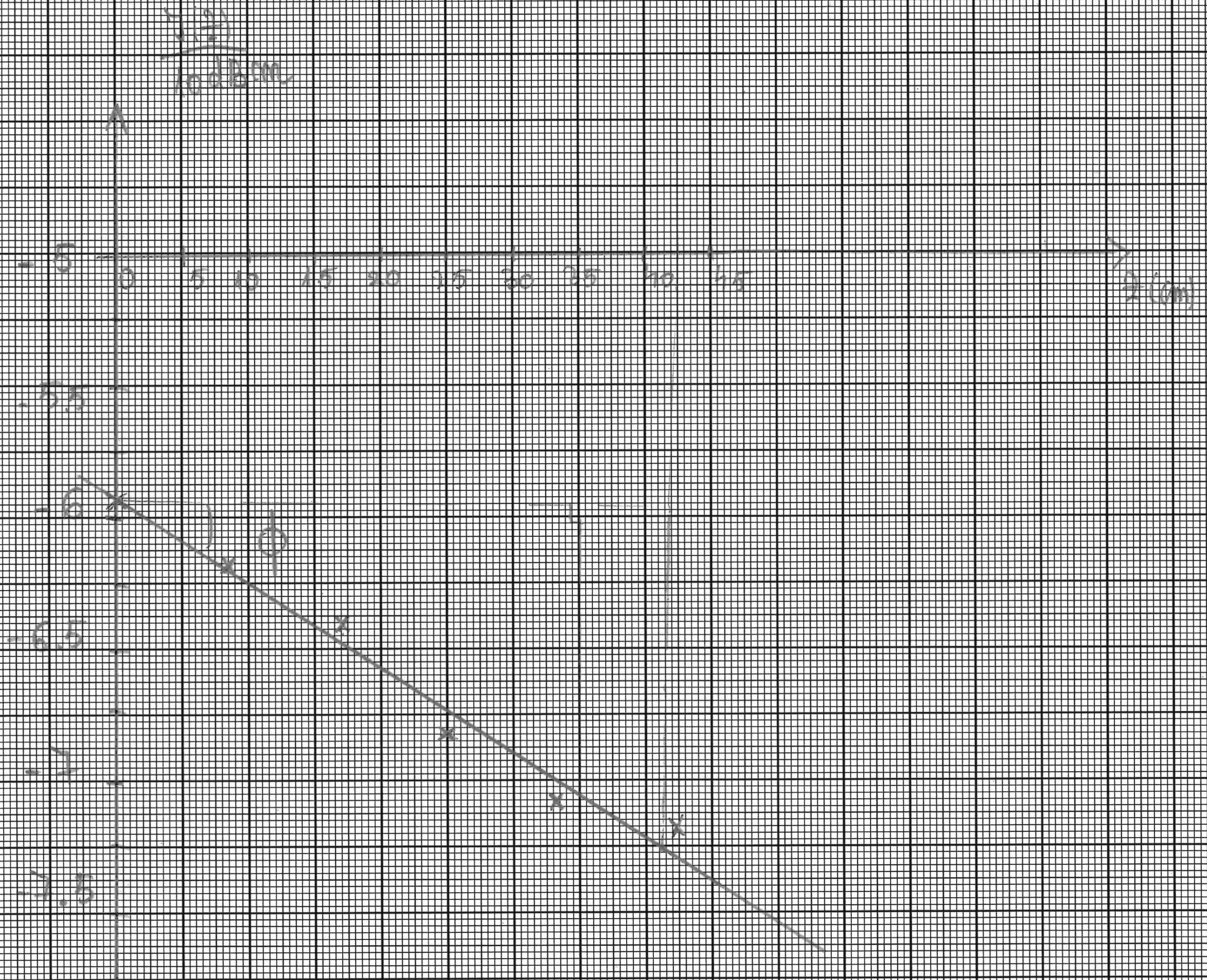
task 3



tan ϕ = b

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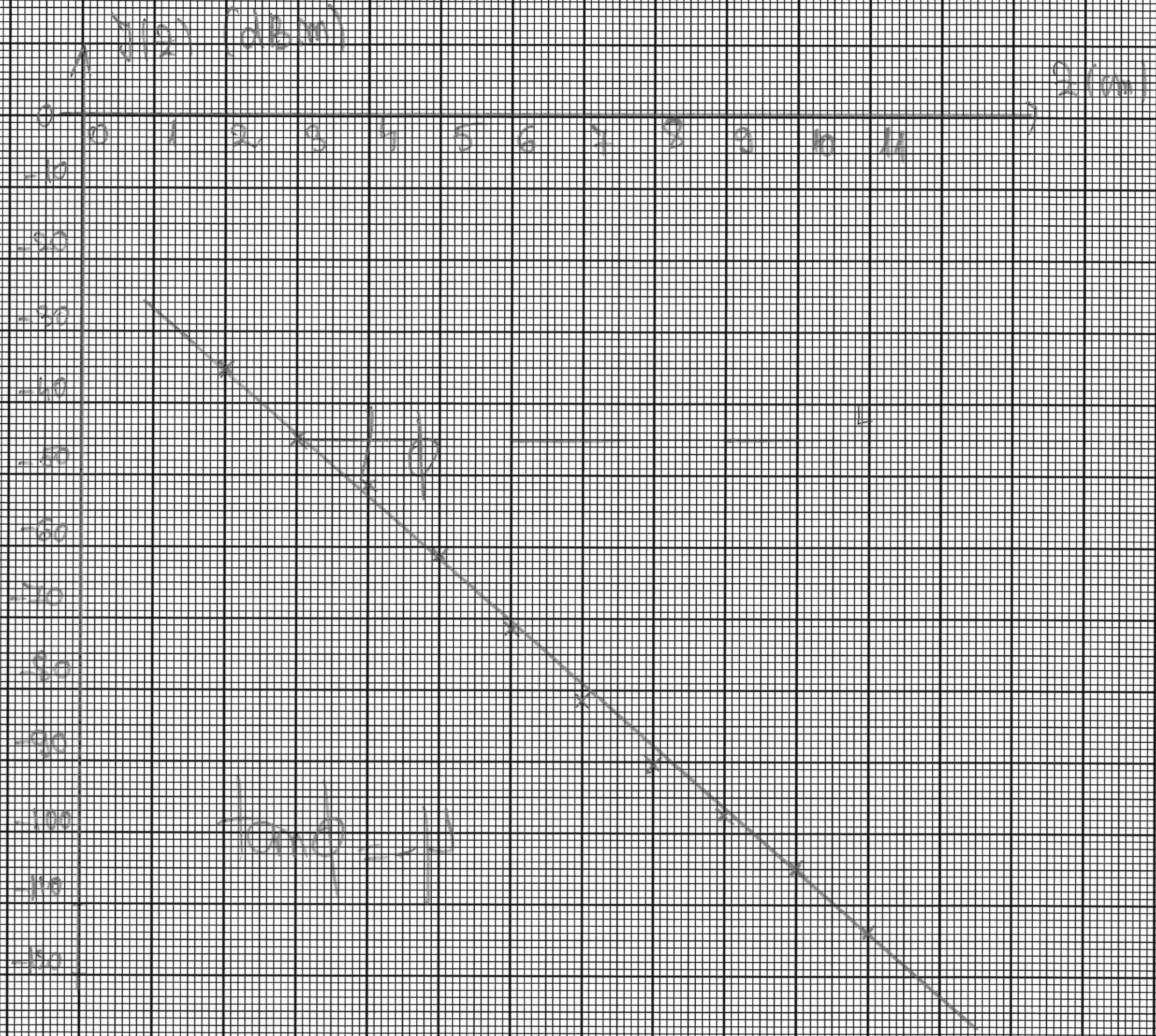
task 4a



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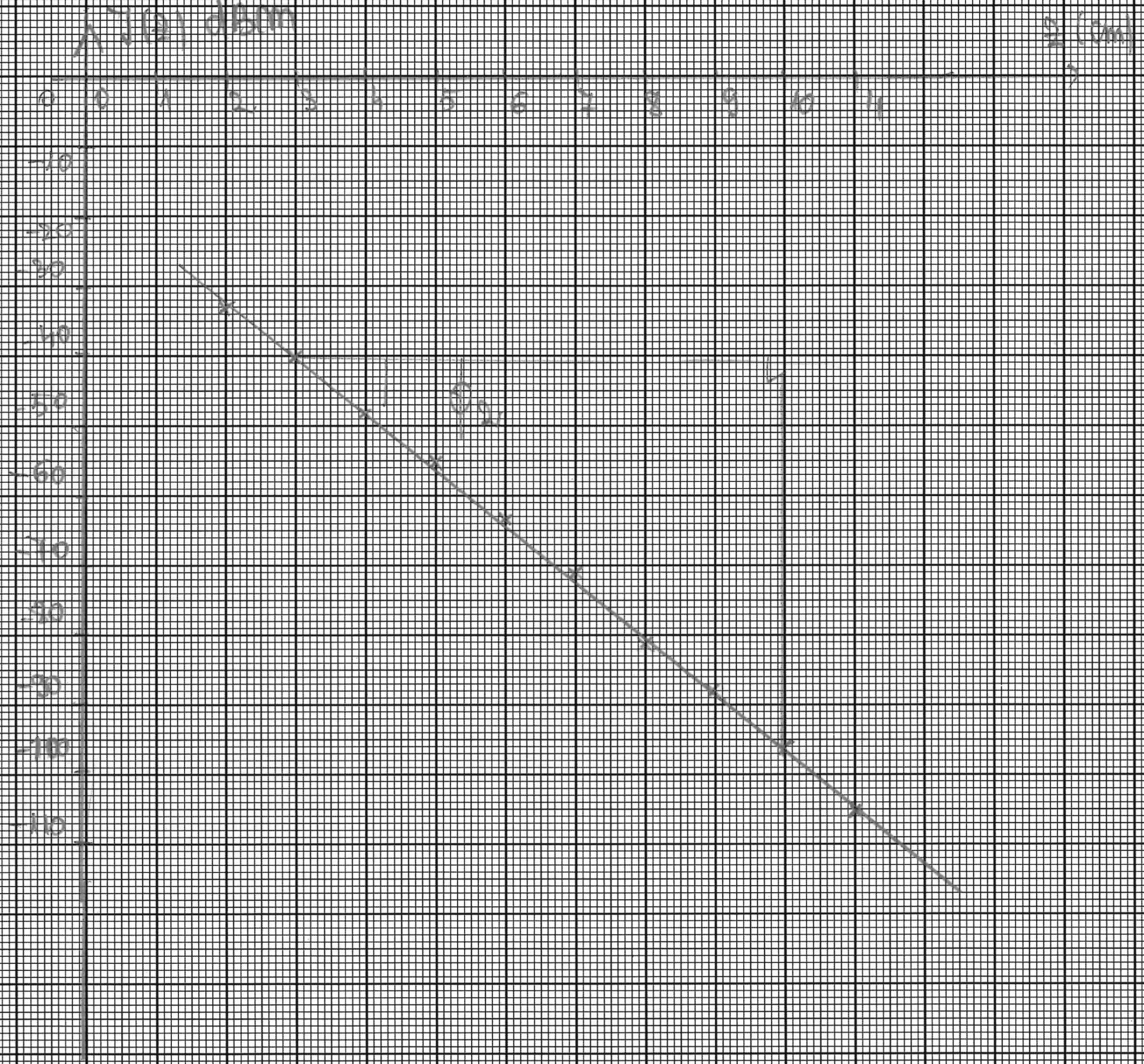
Task 4b.

$d_2 = 46$ mm



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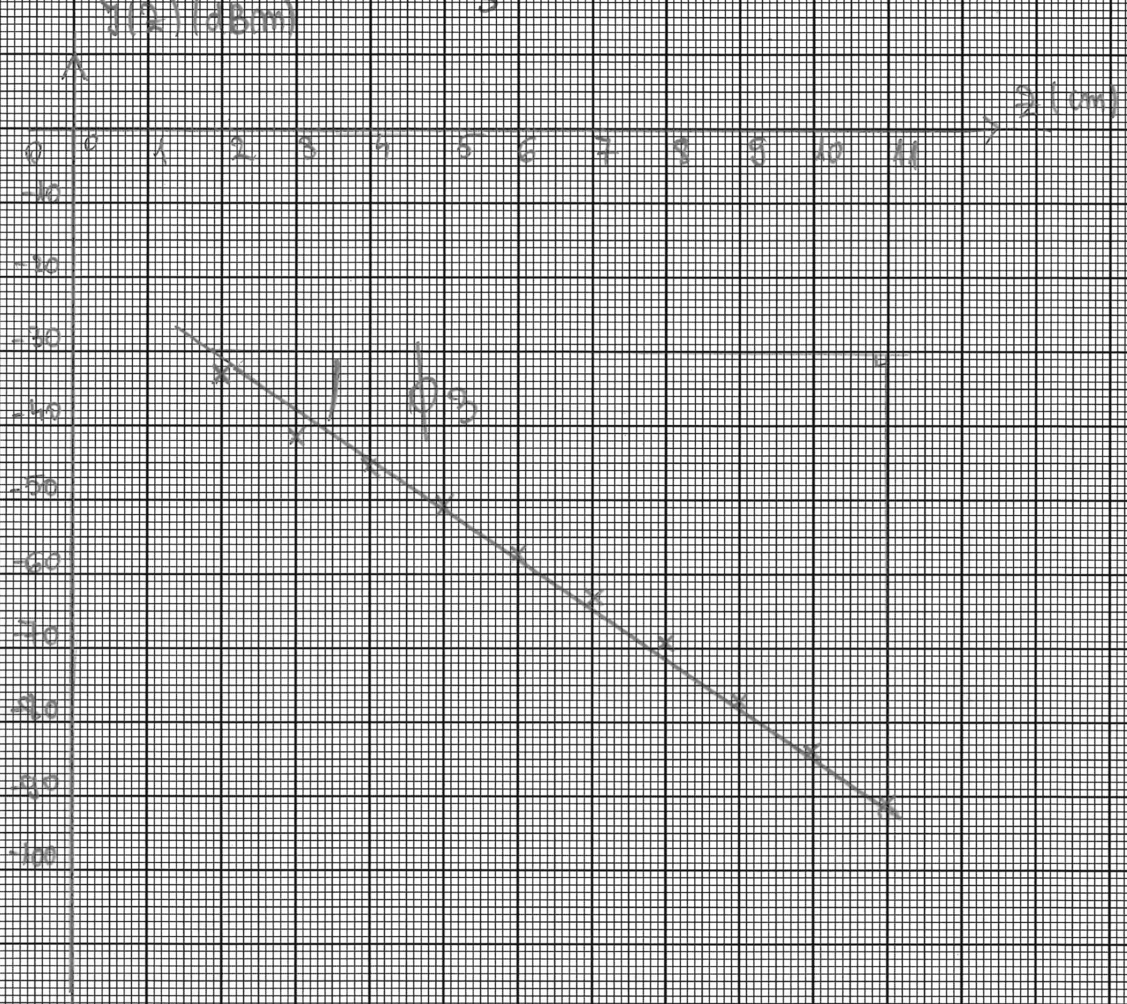
Task 4b

$d_3 = 59\,mm$



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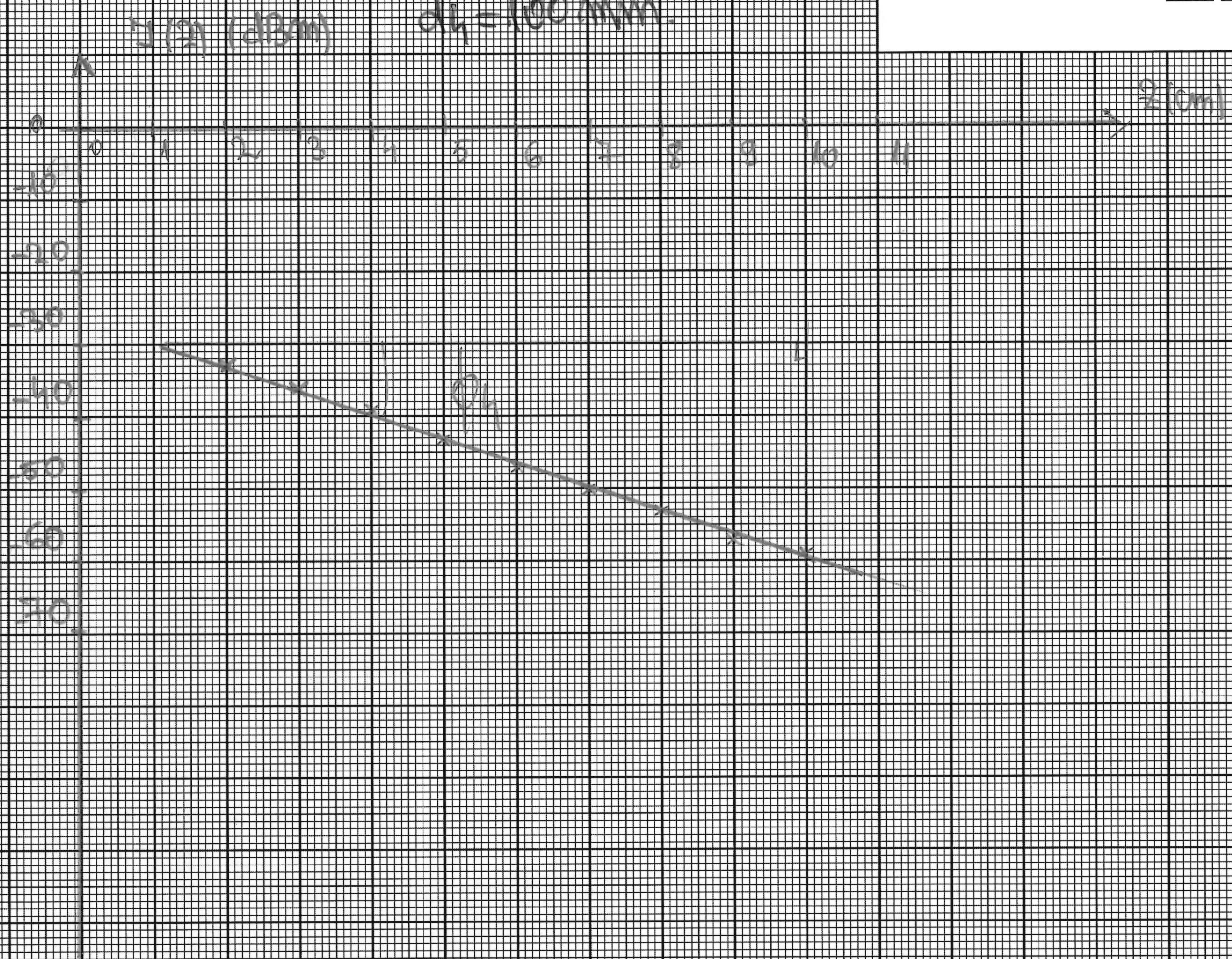
Task 4b

$d_4 = 100$ mm



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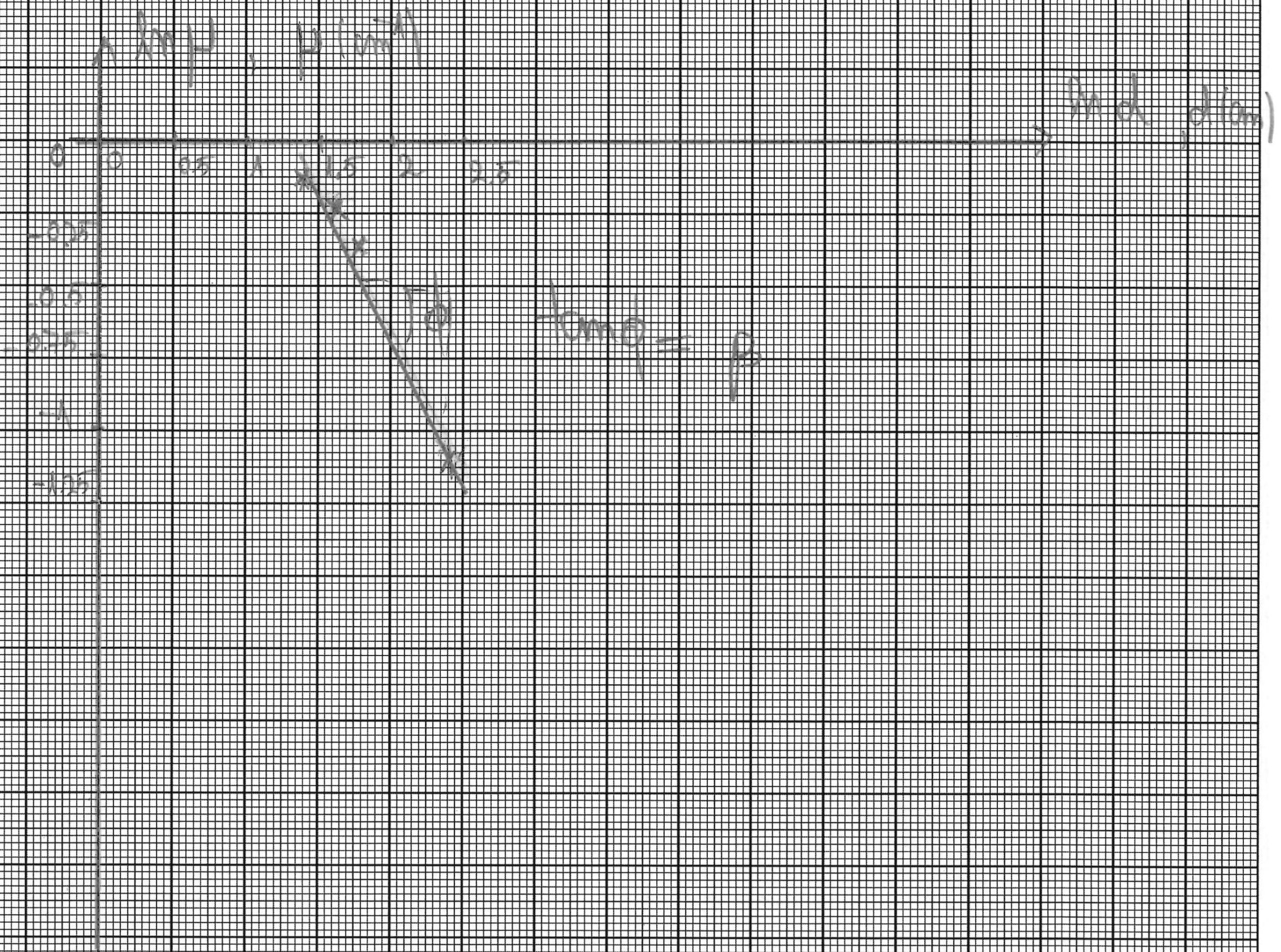
task 4b:



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