

# **PROBLEMS ON PROBABILITY FUNCTION AND DISTRIBUTION FUNCTION**

**Presented  
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## Problem 1:

*For what value of 'a'*

$$f(x) = a \cdot \left(\frac{1}{2}\right)^x, x = 0, 1, 2, \dots \dots$$
$$= 0 \quad , elsewhere$$

*is the probability – mass function of a random variable  $X$  ? Find  $P(X > 0 / X < 2)$ , and mean of  $X$ .*

**Solution:**

Since,  $f(x)$  will be a p.m.f.,

$$so, \sum_x f(x) = 1$$

$$Or, \sum_{x=0}^{\infty} a \cdot \left(\frac{1}{2}\right)^x = 1$$

$$Or, a \cdot \left[1 + \frac{1}{2} + \left(\frac{1}{2}\right)^2 + \left(\frac{1}{2}\right)^3 + \dots\right] = 1$$

$$Or, a \cdot \left(1 - \frac{1}{2}\right)^{-1} = 1; \quad Or, a = \frac{1}{2}.$$

$$\begin{aligned}
P(X > 0 / X < 2) &= \frac{P(X > 0 \cap X < 2)}{P(X < 2)} \\
&= \frac{P(X = 1)}{P(X = 0) + P(X = 1)} \\
&= \frac{\left(\frac{1}{2}\right)^2}{\frac{1}{2} + \left(\frac{1}{2}\right)^2} = \frac{\frac{1}{4}}{\frac{3}{4}} = \frac{1}{3}.
\end{aligned}$$

$$E(X) = \sum_{x=0}^{\infty} x \cdot \left(\frac{1}{2}\right)^{x+1}$$

$$= 1 \cdot \left(\frac{1}{2}\right)^2 + 2 \cdot \left(\frac{1}{2}\right)^3 + 3 \cdot \left(\frac{1}{2}\right)^4 + \dots$$

$$= \left(\frac{1}{2}\right)^2 \left[ 1 + 2 \cdot \frac{1}{2} + 3 \cdot \left(\frac{1}{2}\right)^2 + \dots \right]$$

$$= \left(\frac{1}{2}\right)^2 \left[ 1 - \frac{1}{2} \right]^{-2} = 1.$$

## Problem 2:

$X$  is a discrete random variable having probability – mass function:

| $x$      | 0 | 1   | 2    | 3    | 4    | 5     | 6      | 7        |
|----------|---|-----|------|------|------|-------|--------|----------|
| $P(X=x)$ | 0 | $k$ | $2k$ | $2k$ | $3k$ | $k^2$ | $2k^2$ | $7k^2+k$ |

Determine i) the constant  $k$ , ii)  $P(X < 6)$ ,  
and  $P(X \geq 6)$ .

## Solution:

Since,  $P(X = x)$  is a p.m.f., so,  $\sum_{x=0}^7 P(X = x) = 1$ .

$$\text{Or, } 10k^2 + 9k = 1$$

$$\text{Or, } 10k^2 + 9k - 1 = 0$$

$$\text{Or, } 10k^2 + 10k - k - 1 = 0$$

$$\text{Or, } 10k(k+1) - (k+1) = 0$$

$$\text{Or, } (10k-1)(k+1) = 0 \quad \text{So, } k = -1 \text{ or } k = \frac{1}{10}.$$

Since,  $k$  can not be negative; So,  $k = \frac{1}{10}$ .

$$\begin{aligned}
P(X < 6) &= 1 - P(X \geq 6) = 1 - [P(X = 6) + P(X = 7)] \\
&= 1 - [2 \cdot k^2 + 7k^2 + k] \\
&= 1 - [2 \cdot \left(\frac{1}{10}\right)^2 + 7 \cdot \left(\frac{1}{10}\right)^2 + \frac{1}{10}] \\
&= 1 - \left[\left(\frac{9}{100}\right) + \frac{1}{10}\right] \\
&= 0.81
\end{aligned}$$

$$P(X \geq 6) = 1 - P(X < 6) = 1 - 0.81 = 0.19$$

### Problem 3:

Is the following a probability – density function?

$$f(x) = \frac{x}{2}, \quad 0 < x \leq 1$$

$$= \frac{1}{2}, \quad 1 < x \leq 2$$

$$= \frac{(3-x)}{2}, \quad 2 < x \leq 3.$$

$$= 0, \quad elsewhere$$

**Solution:**

$$\begin{aligned}\int_{-\infty}^{\infty} f(x)dx &= \int_0^1 \frac{x}{2} dx + \int_1^2 \frac{1}{2} dx + \int_2^3 \left(\frac{3-x}{2}\right) dx \\&= \left[\frac{x^2}{4}\right]_0^1 + \left[\frac{x}{2}\right]_1^2 + \left[\frac{3x}{2}\right]_2^3 - \left[\frac{x^2}{4}\right]_2^3 \\&= \frac{1}{4} + 1 - \frac{1}{2} + \frac{9}{2} - \frac{6}{2} - \frac{9}{4} + 1 = \frac{12 - 8}{4} = 1.\end{aligned}$$

Since,  $f(x) \geq 0, \forall x$  and

$$\int_{-\infty}^{\infty} f(x)dx = 1; \text{ so, } f(x) \text{ is a p.d.f.}$$

## Problem 4:

Obtain mean and variance of a continuous random variable  $X$  having the density function

$$\begin{aligned}f(x) &= x, \quad 0 < x \leq 1 \\&= 2 - x, \quad 1 < x \leq 2 \\&= 0, \quad \text{elsewhere}\end{aligned}$$

**Solution:**

$$\begin{aligned}E(X) &= \int_{-\infty}^{\infty} x \cdot f(x) dx \\&= \int_0^1 x^2 dx + \int_1^2 x(2-x) dx \\&= \left[ \frac{x^3}{3} \right]_0^1 + \left[ \frac{2x^2}{2} - \frac{x^3}{3} \right]_1^2 \\&= \frac{1}{3} + 4 - 1 - \frac{8}{3} + \frac{1}{3} \\&= 1\end{aligned}$$

$$E(X^2) = \int_{-\infty}^{\infty} x^2 \cdot f(x) dx$$

$$= \int_0^1 x^3 dx + \int_1^2 x^2 \cdot (2-x) dx = \left[ \frac{x^4}{4} \right]_0^1 + \left[ \frac{2x^3}{3} - \frac{x^4}{4} \right]_1^2$$

$$= \frac{1}{4} + \frac{16}{3} - \frac{2}{3} - 4 + \frac{1}{4} = \frac{3 + 64 - 8 - 48 + 3}{12}$$

$$= \frac{7}{6}$$

$$Var(X) = E(X^2) - E^2(X) = \frac{7}{6} - 1 = \frac{1}{6}$$

## Problem 5:

Suppose a random variable X has the following density function:

$$f(x) = \begin{cases} \frac{1}{b-a}, & a \leq x \leq b \\ 0, & \text{otherwise} \end{cases}$$

Find E(X) and Var(X), and comment on the shape of the distribution. If it is given that a = 2 and b = 7, then from this density function evaluate the following:

- i)  $P(2.5 \leq X \leq 4)$
- ii)  $P(X > 6)$

**Solution:**

$$\begin{aligned} E(X) &= \int_{-\infty}^{\infty} x \cdot f(x) dx \\ &= \int_a^b \frac{x}{b-a} dx = \left[ \frac{x^2}{2(b-a)} \right]_a^b \end{aligned}$$

$$= \left[ \frac{b^2 - a^2}{2(b-a)} \right] = \frac{a+b}{2}$$

$$E(X^2) = \int_{-\infty}^{\infty} x^2 \cdot f(x) dx = \int_a^b \frac{x^2}{b-a} dx$$

$$= \left[ \frac{x^3}{3(b-a)} \right]_a^b = \left[ \frac{b^3 - a^3}{3(b-a)} \right] = \frac{a^2 + ab + b^2}{3}$$

$$Var(X) = E(X^2) - E^2(X)$$

$$= \frac{a^2 + ab + b^2}{3} - \left( \frac{a+b}{2} \right)^2$$

$$= \frac{a^2 + ab + b^2}{3} - \frac{a^2 + 2ab + b^2}{4} = \frac{(a-b)^2}{12}$$

$$\begin{aligned}
\mu_r &= E(X - \mu)^r = \int_a^b \left( x - \frac{a+b}{2} \right)^r \cdot \frac{1}{b-a} dx \\
&= \int_{\frac{-(b-a)}{2}}^{\frac{b-a}{2}} (z)^r \cdot \frac{1}{b-a} dz, \quad \text{Let } \left( x - \frac{a+b}{2} \right) = z; \\
&\quad \text{so, } dx = dz
\end{aligned}$$

$$\begin{aligned}
&= \frac{1}{b-a} \left[ \frac{z^{r+1}}{r+1} \right]_{\frac{-(b-a)}{2}}^{\frac{b-a}{2}} = \frac{1}{b-a} \left[ \frac{\left( \frac{b-a}{2} \right)^{r+1} - \left( -\frac{b-a}{2} \right)^{r+1}}{r+1} \right]
\end{aligned}$$

$$\mu_2 = E(X - \mu)^2 = \frac{1}{3(b-a)} \left[ \left( \frac{b-a}{2} \right)^3 - \left( -\frac{b-a}{2} \right)^3 \right]$$

$$= \frac{(b-a)^2}{12}$$

$$\mu_3 = E(X - \mu)^3 = \frac{1}{4(b-a)} \left[ \left( \frac{b-a}{2} \right)^4 - \left( -\frac{b-a}{2} \right)^4 \right]$$

$$= 0$$

$$\mu_4 = E(X - \mu)^4 = \frac{1}{5(b-a)} \left[ \left( \frac{b-a}{2} \right)^5 - \left( -\frac{b-a}{2} \right)^5 \right]$$

$$= \frac{(b-a)^4}{5.16} = \frac{(b-a)^4}{80}$$

$$\gamma_1 = \sqrt{\beta_1} = \sqrt{\frac{\mu_3^2}{\mu_2^3}} = 0.$$

$$\gamma_2 = \beta_2 - 3 = \frac{\mu_4}{\mu_2^2} - 3 = \frac{80}{(b-a)^4} - 3 = \frac{144}{80} - 3 = -1.2.$$

Since,  $\gamma_1 = 0$  and  $\gamma_2 < 0$ ; so, the distribution is symmetric and platykurtic.

$$P(2.5 \leq X \leq 4) = \int_{2.5}^4 \frac{1}{7-2} dx = \left[ \frac{x}{5} \right]_{2.5}^4$$

$$= \left[ \frac{1.5}{5} \right] = 0.3$$

$$P(X > 6) = \int_6^7 \frac{1}{7-2} dx = \left[ \frac{x}{5} \right]_6^7 = \left[ \frac{1}{5} \right] = 0.2$$

**Problem 6:**

$$\text{If } f(x) = \frac{x}{21} \text{ for } x = 1, 2, 3, 4, 5, 6 \\ = 0, \text{ otherwise}$$

$$\text{Find } P\left(\frac{1}{2} < X < \frac{5}{2} / X > 1\right).$$

**Solution:**

$$P\left(\frac{1}{2} < X < \frac{5}{2} / X > 1\right).$$

$$= \frac{P[(0.5 < X < 2.5) \cap X > 1]}{P(X > 1)} = \frac{P(X = 2)}{1 - P(X = 1)}.$$

$$= \frac{2/21}{1 - (1/21)} = \frac{1}{10} = 0.1.$$

**Problem 7:**

Let  $X$  be a random variable with probability density function given by

$$f(x) = K \cdot e^{-ax} \cdot x^{p-1}, \quad 0 < x < \infty, \quad a > 0, \quad p > 0$$
$$= 0, \quad \text{otherwise}$$

Find  $K$ . Also find  $E(X)$  and  $\text{Var}(X)$ .

**Solution:**

Since,  $f(x)$  is a p.d.f. so,  $\int_{-\infty}^{\infty} f(x)dx = 1$

$$\int_0^{\infty} K \cdot e^{-ax} \cdot x^{p-1} dx = 1 \quad \text{Or, } K \int_0^{\infty} e^{-ax} \cdot x^{p-1} dx = 1$$

$$Or, K \int_0^{\infty} e^{-z} \cdot \left( \frac{z}{a} \right)^{p-1} \cdot \frac{dz}{a} = 1 \quad \text{Let } ax = z. So, dx = \frac{1}{a} dz$$

$$Or, K \cdot \frac{\Gamma p}{a^p} = 1 \quad Or, K = \frac{a^p}{\Gamma p}$$

$$\mu_r' = E(X)^r = \int_{-\infty}^{\infty} x^r \cdot f(x) dx = \int_{-\infty}^{\infty} x^r \cdot K \cdot e^{-ax} \cdot x^{p-1} dx$$

$$= \int_{-\infty}^{\infty} x^r \cdot K \cdot e^{-ax} \cdot x^{p-1} dx = \int_{-\infty}^{\infty} K \cdot e^{-ax} \cdot x^{r+p-1} dx$$

$$= \frac{a^p \cdot \Gamma(r+p)}{a^{r+p} \cdot \Gamma p} = \frac{\Gamma(r+p)}{a^r \cdot \Gamma p}$$

$$\mu_1 = E(X)^1 = \frac{\Gamma(1+p)}{a.\Gamma p} = \frac{p.\Gamma p}{a.\Gamma p} = \frac{p}{a}$$

$$\begin{aligned}\mu_2 &= E(X)^2 = \frac{\Gamma(2+p)}{a^2.\Gamma p} \\ &= \frac{p.(p+1).\Gamma p}{a^2.\Gamma p} = \frac{p(p+1)}{a^2}\end{aligned}$$

$$Variance = \mu_2 - \mu_1^2 = \frac{p(p+1)}{a^2} - \frac{p^2}{a^2} = \frac{p}{a^2}$$

## Problem 8:

Find K and then find mean deviation about mean of the distribution with p.d.f .

$$f(x) = K \cdot x \cdot (2 - x), 0 \leq x \leq 2 \\ = 0, \quad \text{otherwise}$$

## Solution:

Since,  $f(x)$  is a p.d.f. so,  $\int f(x)dx = 1$

$$\int_0^2 K \cdot x \cdot (2 - x) dx = 1 \quad \text{Or, } K \left[ \frac{2x^2}{2} - \frac{x^3}{3} \right]_0^{-\infty} = 1$$

$$Or, K \left[ 4 - \frac{8}{3} \right] = 1 \quad Or, K \left[ \frac{4}{3} \right] = 1$$

$$Or, K = \frac{3}{4}$$

$$Mean = E(X) = \int_0^2 x \cdot \frac{3}{4} \cdot x \cdot (2-x) dx$$

$$= \left[ \frac{3}{4} \left( \frac{2x^3}{3} - \frac{x^4}{4} \right) \right]_0^2 = \left[ \frac{3}{4} \left( \frac{16}{3} - \frac{16}{4} \right) \right] = 1$$

*Mean deviation about mean* =  $E[|X - E(X)|]$

$$= \int_0^2 |x-1| \frac{3}{4} \cdot x \cdot (2-x) dx$$

$$= \int_0^1 (1-x) \frac{3}{4} \cdot x \cdot (2-x) dx + \int_1^2 (x-1) \cdot \frac{3}{4} \cdot x \cdot (2-x) dx$$

$$= \frac{3}{4} \left[ \int_0^1 (x^3 - 3x^2 + 2x) dx + \int_1^2 (3x^2 - 2x - x^3) dx \right]$$

$$= \frac{3}{4} \left[ \frac{x^4}{4} - \frac{3x^3}{3} + \frac{2x^2}{2} \right]_0^1 + \frac{3}{4} \left[ \frac{3x^3}{3} - \frac{2x^2}{2} - \frac{x^4}{4} \right]_1^2$$

$$= \frac{3}{4} \left[ \frac{1}{4} - 1 + 1 \right] + \frac{3}{4} \left[ \frac{3.8}{3} - \frac{2.4}{2} - \frac{16}{4} \right] - \frac{3}{4} \left[ 1 - 1 - \frac{1}{4} \right]$$

$$= \frac{3}{4} \left[ \frac{1}{4} \right] + \frac{3}{4} [8 - 4 - 4] + \frac{3}{4} \cdot \frac{1}{4}$$

$$= \frac{3}{8}$$

## Problem 9:

*A continuous random variable  $X$  has a p.d.f.*

$$f(x) = 3x^2, 0 \leq x \leq 1.$$

*Find  $a$  such that  $P(X \leq a) = P(X > a)$ .*

**Solution:**

$$P(X \leq a) = \int_0^a 3x^2 dx = \left[ \frac{3x^3}{3} \right]_0^a = a^3$$

$$P(X > a) = \int_a^1 3x^2 dx = \left[ \frac{3x^3}{3} \right]_a^1 = 1 - a^3$$

$$\therefore P(X \leq a) = P(X > a)$$

$$Or, a^3 = 1 - a^3$$

$$Or, 2a^3 = 1$$

$$Or, a = \sqrt[3]{\frac{1}{2}}$$

**Problem 10:**

*The joint probability distribution of two discrete random variable is*

$$\begin{aligned}f(x, y) &= \frac{1}{4}, \quad x = 1, y = 0 \\&= \frac{1}{4}, \quad x = 2, y = 3 \\&= \frac{1}{2}, \quad x = 3, y = 5 \\&= 0, \text{ otherwise.}\end{aligned}$$

*Obtain i) marginal distribution of  $Y$ ,  
ii)  $f(x / y = 5)$ , iii)  $\text{Cov}(X, Y)$ .*

## Solution:

| X     | Y | 0   | 3   | 5   | Total |
|-------|---|-----|-----|-----|-------|
| 1     |   | 1/4 | 0   | 0   | 1/4   |
| 2     |   | 0   | 1/4 | 0   | 1/4   |
| 3     |   | 0   | 0   | 1/2 | 1/2   |
| Total |   | 1/4 | 1/4 | 1/2 | 1     |

i) Marginal distribution of  $Y$  is

| Y          | 0   | 3   | 5   | Total |
|------------|-----|-----|-----|-------|
| P( Y = y ) | 1/4 | 1/4 | 1/2 | 1     |

ii) Conditional distribution of  $X$  given  $Y = 5$  is

$$f(x/Y=5) = \frac{P(X=3, Y=5)}{P(Y=5)} = \frac{\frac{1}{2}}{\frac{1}{2}} = 1, x = 3$$

= 0, otherwise.

$$\begin{aligned}ii) Cov(X, Y) &= \sum_x \sum_y x.y.P(X = x, Y = y) \\&= 2.3.\frac{1}{4} + 3.5.\frac{1}{2} \\&= \frac{18}{2} = 9\end{aligned}$$

**Problem 11:** Two continuous random variables  $X$  and  $Y$  have the following joint p.d.f.

$$f(x, y) = \frac{1}{2\pi} e^{-\frac{1}{2}(x^2 + y^2)}, \quad -\infty < x, y < \infty$$

Examine whether the variables are independent or not.

**Solution:**

*M arginal distribution of Y is*

$$\begin{aligned} h(y) &= \int_{-\infty}^{\infty} f(x, y) dx = \int_{-\infty}^{\infty} \frac{1}{2\pi} e^{-\frac{1}{2}(x^2+y^2)} dx \\ &= \frac{1}{2\pi} e^{-\frac{y^2}{2}} \int_{-\infty}^{\infty} e^{-\frac{x^2}{2}} dx \\ &= \frac{1}{2\pi} e^{-\frac{y^2}{2}} \cdot \sqrt{2\pi} \\ &= \frac{1}{\sqrt{2\pi}} e^{-\frac{y^2}{2}}, -\infty < y < \infty \end{aligned}$$

So, marginal distribution of  $X$  is

$$g(x) = \int_{-\infty}^{\infty} f(x, y) dy = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}}, -\infty < x < \infty$$

$\because f(x, y) = g(x).h(y), \forall x, y;$  so,  $X$  and  $Y$  are independent.

## Problem 12:

*Suppose the two random variables  $X$  and  $Y$  have the joint probability density function*

$$f(x, y) = \frac{1}{3}(x + y), \quad 0 \leq x \leq 1, 0 \leq y \leq 2.$$

*Find the marginal probability density function of  $X$ .*

**Solution:**

*M arginal distribution of X is*

$$g(x) = \int_{-\infty}^{\infty} f(x, y) dy = \int_0^2 \frac{1}{3}(x + y) dy$$

$$= \left[ \frac{1}{3} \left( xy + \frac{y^2}{2} \right) \right]_0^2$$

$$= \left[ \frac{1}{3} (2x + 2) \right], 0 \leq x \leq 1$$

### Problem 13:

*The following is the distribution function of a discrete random variable  $X$  :*

|      |      |      |      |      |      |      |      |      |
|------|------|------|------|------|------|------|------|------|
| X    | -3   | -1   | 0    | 1    | 2    | 5    | 8    | 9    |
| F(x) | 0.10 | 0.30 | 0.45 | 0.50 | 0.75 | 0.90 | 0.95 | 1.00 |

*Find i) the probability distribution of  $X$ .  
ii)  $P(-3 \leq X \leq 3)$  and iii)  $P(X \geq 3 / X > 0)$ .*

**Solution:**  $P(X = x) = 0.10,$   $x = -3$

$$P(X = x) = 0.30 - 0.10 = 0.20, \quad x = -1$$

$$P(X = x) = 0.45 - 0.30 = 0.15, \quad x = 0$$

$$P(X = x) = 0.50 - 0.45 = 0.05, \quad x = 1$$

$$P(X = x) = 0.75 - 0.50 = 0.25, \quad x = 2$$

$$P(X = x) = 0.90 - 0.75 = 0.15, \quad x = 5$$

$$P(X = x) = 0.95 - 0.90 = 0.05, \quad x = 8$$

$$P(X = x) = 1.00 - 0.95 = 0.05, \quad x = 9$$

$$ii) P(-3 \leq X \leq 3)$$

$$= 1 - [P(X = 5) + P(X = 8) + P(X = 9)]$$

$$= 1 - [0.15 + 0.05 + 0.05]$$

$$= 0.75$$

$$iii) P(X \geq 3 / X > 0) = \frac{P(X \geq 3 \cap X > 0)}{P(X > 0)}.$$

$$= \frac{P(X = 5) + P(X = 8) + P(X = 9)}{1 - [P(X = -3) + P(X = -1) + P(X = 0)]}.$$

$$= \frac{0.25}{1 - (0.10 + 0.20 + 0.15)} = \frac{0.25}{0.55} = \frac{5}{11}$$

**Problem 14:** Obtain probability functions from the following distribution function:

$$F(x) = 0, x < 1$$

$$= \frac{1}{4}, 1 \leq x < 4$$

$$= \frac{3}{4}, 4 \leq x < 6$$

$$= 1, x \geq 6.$$

$$F(x) = 0, x \leq 0$$

$$= \frac{x^2}{2}, 0 < x \leq 1$$

$$= \frac{x}{2}, 1 < x \leq 2$$

$$= 1, x > 2.$$

## Solution:

$$\begin{aligned}P(X = x) &= \frac{1}{4}, \quad x = 1 \\&= \frac{3}{4} - \frac{1}{4} = \frac{2}{4} = \frac{1}{2}, \quad x = 4 \\&= 1 - \frac{3}{4} = \frac{1}{4}, \quad x = 6 \\&= 0, \text{ otherwise}\end{aligned}$$

$$\begin{aligned}f(x) &= \frac{dF(x)}{dx} = x, \quad 0 < x \leq 1 \\&= \frac{1}{2}, \quad 1 < x \leq 2 \\&= 0, \quad \text{otherwise}\end{aligned}$$

**Problem 15:** Evaluate the distribution functions for the following probability functions :

$$f(x) = \frac{1}{8}, x = -1$$

$$= \frac{1}{8}, x = 0$$

$$= \frac{1}{8}, x = 2$$

$$= \frac{5}{8}, x = 4$$

$$= 0, \text{otherwise}$$

$$f(x) = \frac{1}{k} e^{-\frac{x}{k}}, 0 < x, k > 0$$
$$= 0, \text{otherwise}$$

**Solution:**

$$F(x) = 0, x < -1$$

$$= \frac{1}{8}, -1 \leq x < 0$$

$$= \frac{1}{8} + \frac{1}{8} = \frac{1}{4}, 0 \leq x < 2$$

$$= \frac{2}{8} + \frac{1}{8} = \frac{3}{8}, 2 \leq x < 4$$

$$= \frac{3}{8} + \frac{5}{8} = 1, x \geq 4.$$

$$F(x) = \int_0^x \frac{1}{k} e^{-\frac{t}{k}} dt = \left[ \frac{1}{k} e^{-\frac{t}{k}} \cdot (-k) \right]_0^x = 1 - e^{-\frac{x}{k}}, \quad 0 < x$$
$$= 0, \quad x \leq 0$$

# THANK YOU

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