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**Things allowed (Hjälpmedel):** a calculator.

**Scores rating (Betygsgränser):** 8-11 points giving rate 3; 11.5-14.5 points giving rate 4; 15-18 points giving rate 5.

Write down all necessary steps in solutions in order to receive as many points as possible.

## 1 (3 points)

In a box there are 4 black balls and 6 white balls. A person randomly takes 3 balls out of the box in two different ways:

(1.1) (1p) without replacement (i.e. once a ball is taken then it will be put outside of the box), find the probability that there are exactly 2 black balls in these 3 chosen balls.

(1.2) (2p) with replacement (i.e. once a ball is taken then it will be put back into the box after the color is recorded), find the probability that there are exactly 2 black balls in these 3 chosen balls.

*Solution.* (1.1) This is hypergeometric distribution, and we have

$$P(\text{exactly 2 black}) = \frac{\binom{4}{2} \binom{6}{1}}{\binom{10}{3}} = \frac{6 \times 6}{120} = \frac{3}{10} = 0.3.$$

(1.2) In this case, if  $X$  denotes the number of black balls in these 3 chosen balls, then  $X \sim \text{Bin}(3, \frac{4}{10})$ . Therefore

$$P(\text{exactly 2 black}) = P(X = 2) = \binom{3}{2} \left(\frac{4}{10}\right)^2 \left(1 - \frac{4}{10}\right)^1 = \frac{3 \times 16 \times 6}{1000} = 0.288.$$

□

## 2 (3 points)

Suppose that in Linköping 50% residents are smokers. Among these smokers, 20% of them are heavy smokers (who smoke 25 or more cigarettes a day) and 80% of them are light smokers.

(2.1) (1p) Assume that you randomly meet 10 residents in Linköping. What is the probability that you meet exactly 2 smokers?

(2.2) (2p) Assume that you randomly meet 120 residents in Linköping. What is the probability that you meet at most 15 heavy smokers?

*Solution.* (2.1) Let  $X$  denote the number of smokers among 10 random residents, then  $X \sim \text{Bin}(10, 50\%)$ . Therefore,

$$P(\text{exactly 2 smokers}) = P(X = 2) = \binom{10}{2} (50\%)^2 (1 - 50\%)^8 = 45 \cdot 0.5^{10} = 0.0439.$$

The above value can be also obtained from the Binomial table.

(2.2) Let  $Y$  denote the number of heavy smokers among 120 random residents, then  $Y \sim \text{Bin}(120, 50\% \cdot 20\%)$ . Therefore,

$$\begin{aligned} P(\text{at most 15 heavy smokers}) &= P(Y \leq 15) = P(\text{Bin}(120, 0.1) \leq 15) = P(N(120 \cdot 0.1, 120 \cdot 0.1 \cdot (1 - 0.1)) \leq 15) \\ &= P(N(12, 10.8) \leq 15) \\ &= P(N(0, 1) \leq \frac{15 - 12}{\sqrt{10.8}}) = P(N(0, 1) \leq 0.91) = \Phi(0.91) = 0.8186. \end{aligned}$$

□

### 3 (3 points)

Two events  $A$  and  $B$  have the following probabilities:

$$P(A) = 0.4, \quad P(B) = 0.3, \quad P(A|B) = 0.2.$$

(3.1) (1p) Find the probability  $P(A \cap B)$ .

(3.2) (1p) Find the probability  $P(A \cup B)$ .

(3.3) (1p) Find the conditional probability  $P(B|A)$ .

*Solution.* (3.1) It is from  $P(A|B) = \frac{P(A \cap B)}{P(B)}$  that

$$P(A \cap B) = P(A|B) \cdot P(B) = 0.2 \cdot 0.3 = 0.06.$$

(3.2)

$$P(A \cup B) = P(A) + P(B) - P(A \cap B) = 0.4 + 0.3 - 0.06 = 0.64. \quad (1)$$

(3.3)

$$P(B|A) = \frac{P(B \cap A)}{P(A)} = \frac{P(A \cap B)}{P(A)} = \frac{0.06}{0.4} = 0.15.$$

□

### 4 (3 points)

(4.1) (1p) A population  $X$  is discrete whose distribution is as follows:

$$P(X = 2) = 0.3, \quad P(X = 4) = \theta, \quad P(X = 6) = 0.7 - \theta,$$

where  $0 < \theta < 0.7$  is an unknown parameter. A sample from  $X$  is given as  $\{6, 4, 4, 2, 2\}$ . Estimate  $\theta$  by  $\hat{\theta}_{MM}$  using the Method of Moments.

(4.2) (2p) Another population  $Y$  is continuous whose probability density function is

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

where  $\beta$  is an unknown parameter. A sample  $\{2.15, 3.42, 5.56, 4.28\}$  is taken from this population. Estimate  $\beta$  by  $\hat{\beta}_{ML}$  using the Maximum-Likelihood method.

*Solution.* (4.1) The method of moments reads as  $E(X) = \bar{x}$ , where

$$E(X) = 2 \cdot 0.3 + 4 \cdot \theta + 6 \cdot (0.7 - \theta) = 4.8 - 2\theta, \quad \bar{x} = \frac{6 + 4 + 4 + 2 + 2}{5} = 3.6.$$

This gives that  $4.8 - 2\theta = 3.6$  implying that  $\hat{\theta}_{MM} = 0.6$ .

(4.2) The likelihood function is

$$\begin{aligned} L(\beta) &= f(y_1) \cdot f(y_2) \cdot f(y_3) \cdot f(y_4) = \frac{1}{\sqrt{2\pi}} e^{-\frac{(y_1-\beta)^2}{2}} \cdot \frac{1}{\sqrt{2\pi}} e^{-\frac{(y_2-\beta)^2}{2}} \cdot \frac{1}{\sqrt{2\pi}} e^{-\frac{(y_3-\beta)^2}{2}} \cdot \frac{1}{\sqrt{2\pi}} e^{-\frac{(y_4-\beta)^2}{2}} \\ &= \left( \frac{1}{\sqrt{2\pi}} \right)^4 e^{-\frac{1}{2}[(y_1-\beta)^2 + (y_2-\beta)^2 + (y_3-\beta)^2 + (y_4-\beta)^2]}. \end{aligned}$$

The log likelihood function is

$$\ln L(\beta) = \ln \left( \frac{1}{\sqrt{2\pi}} \right)^4 - \frac{1}{2}[(y_1 - \beta)^2 + (y_2 - \beta)^2 + (y_3 - \beta)^2 + (y_4 - \beta)^2].$$

Then the equation

$$\ln' L(\beta) = (y_1 - \beta) + (y_2 - \beta) + (y_3 - \beta) + (y_4 - \beta) = 0$$

gives

$$\hat{\beta}_{ML} = \frac{y_1 + y_2 + y_3 + y_4}{4} = \bar{y} = \frac{2.15 + 3.42 + 5.56 + 4.28}{4} = 3.8525.$$

□

## 5 (3 points)

Suppose that a sample  $\{4, 2, 6\}$  is taken from a population  $X \sim N(\mu, \sigma^2)$ .

(5.1) (1p) Construct an one-sided 95% confidence interval of  $\mu$  in the form  $I_\mu = (a, +\infty)$ .

(5.2) (2p) Construct an one-sided 95% confidence interval of  $\sigma^2$  in the form  $I_{\sigma^2} = (a, +\infty)$ .

*Solution.* (5.1) With  $\bar{x} = \frac{4+2+6}{3} = 4$  and  $s^2 = \frac{1}{3-1}((4-4)^2 + (2-4)^2 + (6-4)^2) = 4$ , it follows that

$$I_\mu = (\bar{x} - t_\alpha(n-1) \cdot \frac{s}{\sqrt{n}}, +\infty) = (4 - 2.92 \cdot \frac{2}{\sqrt{3}}, +\infty) = (0.6283, +\infty)$$

(5.2) The confidence interval is

$$I_{\sigma^2} = \left( \frac{(n-1)s^2}{\chi_\alpha^2(n-1)}, +\infty \right) = \left( \frac{(3-1) \cdot 4}{5.99}, +\infty \right) = (1.3356, +\infty).$$

□

## 6 (3 points)

Suppose that a sample  $\{4, 2, 6\}$  is taken from a population  $Y \sim N(\mu, 1)$ . Based on this sample, we want to test whether or not  $\mu > 3$ , with a significance level  $\alpha = 5\%$ .

(6.1) (1p) Write down appropriate hypotheses  $H_0$  and  $H_a$ .

(6.2) (1p) Perform the hypotheses testing formulated in (6.1) (Namely, is  $H_0$  rejected? Why?)

(6.3) (1p) Find the power of the test in (6.2) if the true value is  $\mu = 5$ .

*Solution.* (6.1) The hypotheses are:

$$H_0 : \mu = 3 \text{ against } H_a : \mu > 3.$$

(6.2) With  $\bar{x} = \frac{4+2+6}{3} = 4$  and  $\sigma^2 = 1$ , it follows that

$$TS = \frac{\bar{x} - \mu_0}{\sigma/\sqrt{n}} = \frac{4 - 3}{1/\sqrt{3}} = 1.732,$$

$$C = (z_\alpha, +\infty) = (1.64, +\infty).$$

The fact  $TS \in C$  implies that  $H_0$  is rejected (the sample suggests that  $\mu > 3$ ).

An alternative ways is to compute the  $p$ -value and compare it with  $\alpha$ . The  $p$ -value is computed as follows

$$p\text{-value} = P(N(0, 1) \geq TS) = P(N(0, 1) \geq 1.732) = 1 - \Phi(1.73) = 1 - 0.9582 = 0.0418.$$

Note that  $p\text{-value} < \alpha$ , which implies that  $H_0$  is rejected.

(6.3)

$$\begin{aligned} h(5) &= P(H_0 \text{ is rejected when } \mu = 5) = P(TS \in C \text{ when } \mu = 5) = P\left(\frac{\bar{X} - \mu_0}{\sigma/\sqrt{n}} > 1.64 \text{ when } \mu = 5\right) \\ &= P\left(\frac{\bar{X} - \mu + \mu - \mu_0}{\sigma/\sqrt{n}} > 1.64 \text{ when } \mu = 5\right) = P\left(\frac{\bar{X} - \mu}{\sigma/\sqrt{n}} > 1.64 - \frac{\mu - \mu_0}{\sigma/\sqrt{n}} \text{ when } \mu = 5\right) \\ &= P\left(N(0, 1) > 1.64 - \frac{5 - 3}{1/\sqrt{3}}\right) = P(N(0, 1) > -1.82) = 1 - \Phi(-1.82) \\ &= 1 - (1 - \Phi(1.82)) = \Phi(1.82) = 0.9656. \end{aligned}$$

□

## 1. Basic probability

- (1.1) Conditional probability  $P(A|B) = \frac{P(A \cap B)}{P(B)}$ .  
 (1.2) Total probability  $P(B) = \sum_{i=1}^k P(B|A_i)P(A_i)$  where  $\{A_i\}$  are disjoint and  $\cup_{i=1}^k A_i = S$ .  
 (1.3) Bayes' Theorem  $P(A_i|B) = \frac{P(B|A_i)P(A_i)}{\sum_{i=1}^k P(B|A_i)P(A_i)}$  where  $\{A_i\}$  are in (1.2).

## 2. Random variables (r.v.s)

- (2.1) Discrete r.v.  $X$  has a pmf  $p(x) = P(X = x)$  satisfying  $p(x) \geq 0$  and  $\sum p(x_i) = 1$ ,

$$\begin{array}{c|cccc} X & x_1 & x_2 & \cdots & x_n & \cdots \\ \hline p(x) & p(x_1) & p(x_2) & \cdots & p(x_n) & \cdots \end{array}$$

- Expectation (or *Expected value* or *mean*)  $\mu_X = E(X) = \sum x_i p(x_i)$ ;  
 Variance  $\sigma_X^2 = V(X) = E(X - \mu_X)^2 = E(X^2) - \mu_X^2 = \sum x_i^2 p(x_i) - (\sum x_i p(x_i))^2$ .  
 (2.2) Continuous r.v.  $X$  has a pdf  $f(x)$  satisfying  $f(x) \geq 0$  and  $\int_{-\infty}^{\infty} f(x) dx = 1$ ,

$$P(a < X < b) = \int_a^b f(x) dx.$$

Expectation (or *Expected value* or *mean*)  $\mu_X = E(X) = \int_{-\infty}^{\infty} x f(x) dx$ ;

- Variance  $\sigma_X^2 = V(X) = E(X - \mu_X)^2 = E(X^2) - \mu_X^2 = \int_{-\infty}^{\infty} x^2 f(x) dx - (\int_{-\infty}^{\infty} x f(x) dx)^2$ .  
 (2.3) Cumulative distribution function (cdf) of a r.v.  $X$  is  $F(x) = P(X \leq x)$ .  
 (2.4)  $X$  and  $Y$  are r.v.s,  $a, b$  and  $c$  are scalars, then

$$E(aX + bY + c) = aE(X) + bE(Y) + c,$$

$$V(aX + bY + c) = a^2 V(X) + b^2 V(Y) + 2ab \operatorname{cov}(X, Y),$$

$$E(g(X, Y)) = \begin{cases} \sum_{i,j} g(x_i, y_j) \cdot p(x_i, y_j), & \text{for discrete } (X, Y), \\ \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} g(x, y) \cdot f(x, y) dx dy, & \text{for continuous } (X, Y). \end{cases}$$

- (2.5) • Discrete r.v.  $(X, Y)$  has a joint pmf  $p(x, y)$  satisfying  $p(x, y) \geq 0$  and  $\sum_{x_i} \sum_{y_j} p(x_i, y_j) = 1$ .  
 The *marginal pmf* of  $X$  is  $p_X(x) = \sum_y p(x, y)$ ;  
 The *marginal pmf* of  $Y$  is  $p_Y(y) = \sum_x p(x, y)$ ;  
 $X$  and  $Y$  are *independent* if  $p(x, y) = p_X(x) \cdot p_Y(y)$ .  
 • Continuous r.v.  $(X, Y)$  has a joint pdf  $f(x, y)$  satisfying  $f(x, y) \geq 0$  and  $\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y) dx dy = 1$ .  
 The *marginal pdf* of  $X$  is  $f_X(x) = \int_{-\infty}^{\infty} f(x, y) dy$ ;  
 The *marginal pdf* of  $Y$  is  $f_Y(y) = \int_{-\infty}^{\infty} f(x, y) dx$ ;  
 $X$  and  $Y$  are *independent* if  $f(x, y) = f_X(x) \cdot f_Y(y)$ .

## 3. Several special r.v.s

- (3.1)  $X \sim \operatorname{Bin}(n, p)$  has a pmf  $p(x) = P(X = x) = \binom{n}{x} \cdot p^x \cdot (1-p)^{n-x}$ ,  $x = 0, 1, 2, \dots, n$ .  
 $E(X) = n \cdot p$ ,  $V(X) = n \cdot p \cdot (1-p)$ .  
 (3.2)  $X \sim \operatorname{Po}(\lambda)$  has a pmf  $p(x) = P(X = x) = \frac{e^{-\lambda} \lambda^x}{x!}$ ,  $x = 0, 1, 2, \dots$ .  
 $E(X) = \lambda$ ,  $V(X) = \lambda$ .

- (3.3)  $X \sim \operatorname{Hypergeometric}$  has a pmf  $p(x) = P(X = x) = \frac{\binom{M}{x} \binom{N-M}{n-x}}{\binom{N}{n}}$ .

- (3.4)  $X \sim \operatorname{Exp}(\lambda)$  has a pdf

$$f(x) = \begin{cases} \lambda e^{-\lambda x}, & x \geq 0, \\ 0, & \text{otherwise.} \end{cases}$$

- (3.5)  $X \sim N(\mu, \sigma^2)$  has a pdf

$$f(x) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}, \quad -\infty < x < \infty.$$

- (3.6)  $X \sim U(a, b)$  has a pdf

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

$$E(X) = \frac{a+b}{2}, \quad V(X) = \frac{(b-a)^2}{12}.$$

## 4. Central Limit Theorem (CLT)

Suppose that a population has mean  $= \mu$  and variance  $= \sigma^2$ . A random sample  $\{X_1, X_2, \dots, X_n\}$  from this population is given. Then for large  $n \geq 30$ ,

$$\frac{\bar{X} - \mu}{\sigma/\sqrt{n}} \sim N(0, 1). \tag{1}$$

- If the population is normal, then (1) holds for any  $n$ .
- Note that  $\mu = E(\bar{X})$  and  $(\sigma/\sqrt{n})^2 = V(\bar{X})$ .

## 5. Several notations in statistics

- (5.1) Sample mean:  $\bar{X} = \frac{X_1 + X_2 + \dots + X_n}{n} = \sum \bar{X}_i$ ;  $\bar{x} = \frac{x_1 + x_2 + \dots + x_n}{n} = \sum x_i$ .  
 (5.2) Sample variance:

$$S^2 = \frac{\sum (X_i - \bar{X})^2}{n-1} = \frac{1}{n-1} \left( \sum X_i^2 - \frac{(\sum X_i)^2}{n} \right); \quad s^2 = \frac{\sum (x_i - \bar{x})^2}{n-1} = \frac{1}{n-1} \left( \sum x_i^2 - \frac{(\sum x_i)^2}{n} \right).$$

- Capital letters  $\bar{X}$  and  $S^2$  refer to the objects based on random sample (therefore they are in general r.v.s), while small letters  $\bar{x}$  and  $s^2$  are the objects based on observations (so they are scalars).
- (5.3) A point estimator of  $\theta$  obtained by Methods of Moments is denoted as  $\hat{\theta}_{MM}$ .
- (5.4) A point estimator of  $\theta$  obtained by Maximum Likelihood method is denoted as  $\hat{\theta}_{ML}$ .

## 6. Confidence Interval (CI)

In this course, three types of confidence intervals are studied depending on the unknown population parameter(s): CI-1 (confidence intervals for population mean(s)), CI-2 (confidence intervals for population variance(s)), and CI-3 (confidence intervals for population proportion(s)).

**CI-1: (1 - α) CI of a population mean μ**

**case 1.1 (any n)** If population  $X \sim N(\mu, \sigma^2)$  and  $\sigma^2$  is known, then  $\frac{\bar{X}-\mu}{\sigma/\sqrt{n}} \sim N(0, 1)$  and

$$I_\mu = (\bar{x} - z_{\alpha/2} \cdot \frac{\sigma}{\sqrt{n}}, \bar{x} + z_{\alpha/2} \cdot \frac{\sigma}{\sqrt{n}}) := \bar{x} \mp z_{\alpha/2} \cdot \frac{\sigma}{\sqrt{n}}.$$

**case 1.2 (n ≥ 30)** For any population  $X$ , it holds that  $\frac{\bar{X}-\mu}{\sigma/\sqrt{n}} \sim N(0, 1)$  and

$$I_\mu = \bar{x} \mp z_{\alpha/2} \cdot \frac{\sigma}{\sqrt{n}} \text{ or } I_\mu = \bar{x} \mp z_{\alpha/2} \cdot \frac{\hat{\sigma}}{\sqrt{n}}.$$

**case 1.3 (any n)** If population  $X \sim N(\mu, \sigma^2)$  and  $\sigma^2$  is unknown, then  $\frac{\bar{X}-\mu}{S/\sqrt{n}} \sim T(n-1)$  and

$$I_\mu = \bar{x} \mp t_{\alpha/2}(n-1) \cdot \frac{s}{\sqrt{n}}.$$

**CI-1': (1 - α) CI of the difference of two population means  $\mu_X - \mu_Y$**

**case 1.1' (any  $n_1, n_2$ )** If independent populations  $X \sim N(\mu_X, \sigma_X^2)$ ,  $Y \sim N(\mu_Y, \sigma_Y^2)$ , and  $\sigma_X^2, \sigma_Y^2$  are known, then

$$\frac{(\bar{X}-\bar{Y})-(\mu_X-\mu_Y)}{\sqrt{\frac{\sigma_X^2}{n_1} + \frac{\sigma_Y^2}{n_2}}} \sim N(0, 1), \text{ and } I_{\mu_X-\mu_Y} = (\bar{x}-\bar{y}) \mp z_{\alpha/2} \cdot \sqrt{\frac{\sigma_X^2}{n_1} + \frac{\sigma_Y^2}{n_2}}.$$

**case 1.2' ( $n_1, n_2 \geq 30$ )** For any independent populations  $X$  and  $Y$ , it holds that

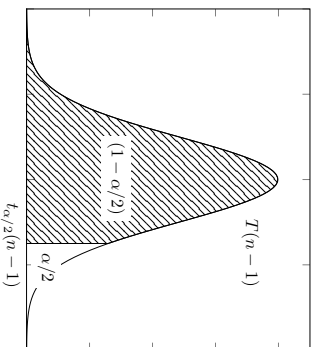
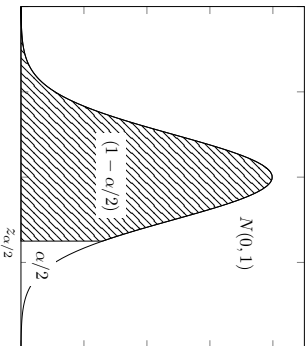
$$\frac{(\bar{X}-\bar{Y})-(\mu_X-\mu_Y)}{\sqrt{\frac{\sigma_X^2}{n_1} + \frac{\sigma_Y^2}{n_2}}} \sim N(0, 1) \text{ and}$$

$$I_{\mu_X-\mu_Y} = (\bar{x}-\bar{y}) \mp z_{\alpha/2} \cdot \sqrt{\frac{\sigma_X^2}{n_1} + \frac{\sigma_Y^2}{n_2}} \text{ or } I_{\mu_X-\mu_Y} = (\bar{x}-\bar{y}) \mp z_{\alpha/2} \cdot \sqrt{\frac{\hat{\sigma}_X^2}{n_1} + \frac{\hat{\sigma}_Y^2}{n_2}}.$$

**case 1.3' (any  $n_1, n_2$ )** If independent populations  $X \sim N(\mu_X, \sigma_X^2)$ ,  $Y \sim N(\mu_Y, \sigma_Y^2)$ , where  $\sigma_X^2, \sigma_Y^2$  are unknown but  $\sigma_X^2 = \sigma_Y^2$ , then

$$\frac{(\bar{X}-\bar{Y})-(\mu_X-\mu_Y)}{S\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \sim T(n_1+n_2-2), \text{ where } S^2 = \frac{(n_1-1)S_X^2 + (n_2-1)S_Y^2}{n_1+n_2-2}, \text{ and}$$

$$I_{\mu_X-\mu_Y} = (\bar{x}-\bar{y}) \mp t_{\alpha/2}(n_1+n_2-2) \cdot s\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}.$$



**CI-2: (1 - α) CI of population variance(s)  $\sigma^2$**

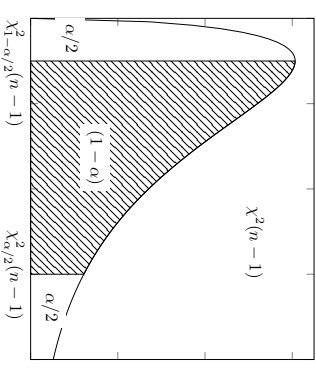
• If a population  $X \sim N(\mu, \sigma^2)$  and  $\sigma^2$  is unknown, then  $\frac{(n-1)S^2}{\sigma^2} \sim \chi^2(n-1)$ , and

$$I_{\sigma^2} = \left( \frac{(n-1)s^2}{\chi_{\alpha/2}^2(n-1)}, \frac{(n-1)s^2}{\chi_{1-\alpha/2}^2(n-1)} \right).$$

• If two independent populations  $X \sim N(\mu_X, \sigma^2)$  and  $Y \sim N(\mu_Y, \sigma^2)$ , and  $\sigma^2$  is unknown, then  $\frac{(n_1+n_2-2)S^2}{\sigma^2} \sim \chi^2(n_1+n_2-2)$ , and

$$I_{\sigma^2} = \left( \frac{(n_1+n_2-2)s^2}{\chi_{\alpha/2}^2(n_1+n_2-2)}, \frac{(n_1+n_2-2)s^2}{\chi_{1-\alpha/2}^2(n_1+n_2-2)} \right),$$

where  $S^2 = \frac{(n_1-1)S_X^2 + (n_2-1)S_Y^2}{n_1+n_2-2}$ .



**CI-3: (1 - α) CI of population proportion(s)**

• If a (large) population has an unknown proportion  $p$ , then  $\frac{\hat{p}-p}{\sqrt{p(1-p)/n}} \sim N(0, 1)$  if  $n\hat{p} \geq 10$  and  $n(1-\hat{p}) \geq 10$  with  $\hat{p} = x/n$ , and  $I_p = \hat{p} \mp z_{\alpha/2} \cdot \sqrt{\frac{\hat{p}(1-\hat{p})}{n}}$ .

• If two independent (large) populations have unknown proportions  $p_1$  and  $p_2$ , then

$$\frac{(\hat{p}_1-\hat{p}_2)-(p_1-p_2)}{\sqrt{\frac{\hat{p}_1(1-\hat{p}_1)}{n_1} + \frac{\hat{p}_2(1-\hat{p}_2)}{n_2}}} \sim N(0, 1)$$

if  $n_i\hat{p}_i \geq 10$  and  $n_i(1-\hat{p}_i) \geq 10$  for  $i = 1, 2$ , and  $I_{p_1-p_2} = (\hat{p}_1-\hat{p}_2) \mp z_{\alpha/2} \cdot \sqrt{\frac{\hat{p}_1(1-\hat{p}_1)}{n_1} + \frac{\hat{p}_2(1-\hat{p}_2)}{n_2}}$ .

**7. Hypothesis Test (HT)**

	$H_0$ is true	$H_0$ is false and $\theta = \theta_1$
reject $H_0$	(type I error or significance level) $\alpha$	(power) $h(\theta_1)$
don't reject $H_0$	$1 - \alpha$	(type II error) $\beta(\theta_1) = 1 - h(\theta_1)$

reject  $H_0 \Leftrightarrow TS \in C \Leftrightarrow p\text{-value} < \alpha$

**$\chi^2$  tests for populations (non-parametric tests)**

Suppose that for a random sample of a population  $X$ , the  $n$  elements of it are classified into  $k$  disjoint groups  $A_i, 1 \leq i \leq k$ . For each group  $A_i, 1 \leq i \leq k$ , suppose that there are  $N_i, 1 \leq i \leq k$  elements inside. Let  $p_i = P(A_i)$  assuming a given distribution of  $X$ . Note that  $p_1 + p_2 + \dots + p_k = 1$  and  $N_1 + N_2 + \dots + N_k = n$ . One wants to test the hypotheses

$$H_0 : P(A_i) = p_i, \quad 1 \leq i \leq k, \quad H_a : P(A_i) \neq p_i \text{ for some } 1 \leq i \leq k.$$

If  $n$  is large in the sense that  $np_i \geq 5$  for all  $1 \leq i \leq k$ , then the test statistic is

$$\sum_{i=1}^k \frac{(N_i - np_i)^2}{np_i} \approx \chi^2(k-1).$$

Therefore the observation of the test statistic is

$$TS = \sum_{i=1}^k \frac{(n_i - np_i)^2}{np_i}, \text{ where } n_i \text{ is the observation of } N_i, 1 \leq i \leq k.$$

For the critical region  $C$ , one can take (note that if  $H_0$  is true, then  $TS$  should be close to zero)

$$C = (\chi^2_{\alpha}(k-1), \infty).$$

The conclusion would be  $TS \in C \iff H_0$  is rejected.

## 8. Linear and logistic regression

**(Multiple) linear regression:**  $Y = \beta_0 + \beta_1 x_1 + \dots + \beta_k x_k + \varepsilon$ ,  $\varepsilon \sim N(0, \sigma^2)$ .

- $Y$  : response variable (which is normal r.v.),  $\{x_1, \dots, x_k\}$  : predictors (which are scalars).
- sample:  $\{(x_{11}, \dots, x_{1k}; y_1), (x_{21}, \dots, x_{2k}; y_2), \dots, (x_{n1}, \dots, x_{nk}; y_n)\}$ .
- how to estimate  $\beta_j \approx \hat{\beta}_j$  : least square method, that is, to minimize  $\sum_{i=1}^n (y_i - \hat{y}_i)^2$ , where the estimated (multiple) linear regression line  $\hat{y}$  is

$$\hat{y} = \hat{\beta}_0 + \hat{\beta}_1 x_1 + \dots + \hat{\beta}_k x_k.$$

- $\frac{\hat{\beta}_j - \beta_j}{se(\hat{\beta}_j)} \sim T(n-k-1)$ , this helps determine whether or not the real  $\beta_j = 0$ ?
- $\sigma^2 \approx \frac{SSE}{n-k-1}$ , this gives an estimation of the size of the error.
- $R^2 = \frac{SSR}{SSY}$ , this gives how well the model is (if  $R^2 \approx 1$ , then the model fits the sample very well).
- How to test  $\beta_1 = \dots = \beta_k = 0$  ? Use the random variable  $\frac{SSR/k}{SSE/(n-k-1)} \sim F(k, n-k-1)$ .

**Logistic regression:** Let  $Y$  can only take 0 or 1 with  $P(Y=1) = p$  and  $P(Y=0) = 1-p$ .

$$E(Y) = p(x_1, \dots, x_k) = \frac{e^{\beta_0 + \beta_1 x_1 + \dots + \beta_k x_k}}{1 + e^{\beta_0 + \beta_1 x_1 + \dots + \beta_k x_k}}.$$

- $Y$  : response variable (which is Bernoulli r.v.  $P(Y=1) = p$  and  $P(Y=0) = 1-p$ , so  $E(Y) = p$ ),  $\{x_1, \dots, x_k\}$  : predictors (which are scalars).
- sample:  $\{(x_{11}, \dots, x_{1k}; y_1), (x_{21}, \dots, x_{2k}; y_2), \dots, (x_{n1}, \dots, x_{nk}; y_n)\}$ .
- how to estimate  $\beta_j \approx \hat{\beta}_j$  : maximal likelihood method (maximize  $\prod_{i=1}^n p(x_{i1}, \dots, x_{ik})^{y_i} (1 - p(x_{i1}, \dots, x_{ik}))^{1-y_i}$ ).
- $\frac{\hat{\beta}_j - \beta_j}{se(\hat{\beta}_j)} \approx N(0, 1)$  for large  $n \geq 30$ , this helps determine whether or not the real  $\beta_j = 0$ ?
- Classification of a new object  $Y(x_1, \dots, x_k)$  as 1 or 0 according

$$Y(x_1, \dots, x_k) = \begin{cases} 1, & \text{if } \hat{p}(x_1, \dots, x_k) \geq 0.5, \\ 0, & \text{if } \hat{p}(x_1, \dots, x_k) < 0.5, \end{cases}$$

where the estimated logit function  $\hat{p}(x_1, \dots, x_k)$  is

$$\hat{p}(x_1, \dots, x_k) = \frac{e^{\hat{\beta}_0 + \hat{\beta}_1 x_1 + \dots + \hat{\beta}_k x_k}}{1 + e^{\hat{\beta}_0 + \hat{\beta}_1 x_1 + \dots + \hat{\beta}_k x_k}}.$$

## 9. Tables

(9.1) Table for  $N(0, 1)$  standard normal random variable  $\Phi(x) = P(N(0, 1) \leq x)$ ,  $x \geq 0$ .  
There is an important relation  $\Phi(-x) = 1 - \Phi(x)$ ,  $x \geq 0$ .

x	0	1	2	3	4	5	6	7	8	9
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9564	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9993	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998	0.9998	0.9998
3.5	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
3.6	0.9998	0.9998	0.9998	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
3.7	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
3.8	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
3.9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
4.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

(9.2) Table for  $T(f)$  random variable  $F(x) = P(T(f) \leq x)$ ,  
where  $f$  is a parameter called 'degrees of freedom'.

f	0.75	0.90	0.95	0.975	0.99	0.995	0.9975	0.9995
1	1.00	3.08	6.31	12.71	31.82	63.66	127.32	636.62
2	0.82	1.89	2.92	4.30	6.96	9.92	14.09	31.60
3	0.76	1.64	2.35	3.18	4.54	5.84	7.45	12.92
4	0.74	1.53	2.13	2.78	3.75	4.60	5.60	8.61
5	0.73	1.48	2.02	2.57	3.36	4.03	4.77	6.87
6	0.72	1.44	1.94	2.45	3.14	3.71	4.32	5.96
7	0.71	1.41	1.89	2.36	3.00	3.50	4.03	5.41
8	0.71	1.40	1.86	2.31	2.90	3.36	3.83	5.04
9	0.70	1.38	1.83	2.26	2.82	3.25	3.69	4.78
10	0.70	1.37	1.81	2.23	2.76	3.17	3.58	4.59
11	0.70	1.36	1.80	2.20	2.72	3.11	3.50	4.44
12	0.70	1.36	1.78	2.18	2.68	3.05	3.43	4.32
13	0.69	1.35	1.77	2.16	2.65	3.01	3.37	4.22
14	0.69	1.35	1.76	2.14	2.62	2.98	3.33	4.14
15	0.69	1.34	1.75	2.13	2.60	2.95	3.29	4.07
16	0.69	1.34	1.75	2.12	2.58	2.92	3.25	4.01
17	0.69	1.33	1.74	2.11	2.57	2.90	3.22	3.97
18	0.69	1.33	1.73	2.10	2.55	2.88	3.20	3.92
19	0.69	1.33	1.73	2.09	2.54	2.86	3.17	3.88
20	0.69	1.33	1.72	2.09	2.53	2.85	3.15	3.85
21	0.69	1.32	1.72	2.08	2.52	2.83	3.14	3.82
22	0.69	1.32	1.72	2.07	2.51	2.82	3.12	3.79
23	0.69	1.32	1.71	2.07	2.50	2.81	3.10	3.77
24	0.68	1.32	1.71	2.06	2.49	2.80	3.09	3.75
25	0.68	1.32	1.71	2.06	2.49	2.79	3.08	3.73
26	0.68	1.31	1.71	2.06	2.48	2.78	3.07	3.71
27	0.68	1.31	1.70	2.05	2.47	2.77	3.06	3.69
28	0.68	1.31	1.70	2.05	2.47	2.76	3.05	3.67
29	0.68	1.31	1.70	2.05	2.46	2.76	3.04	3.66
30	0.68	1.31	1.70	2.04	2.46	2.75	3.03	3.65
40	0.68	1.30	1.68	2.02	2.42	2.70	2.97	3.55
50	0.68	1.30	1.68	2.01	2.40	2.68	2.94	3.50
60	0.68	1.30	1.67	2.00	2.39	2.66	2.91	3.46
100	0.68	1.29	1.66	1.98	2.36	2.63	2.87	3.39
$\infty$	0.67	1.28	1.65	1.96	2.33	2.58	2.81	3.29

(9.3) Table for  $\chi^2(f)$  random variable  $F(x) = P(\chi^2(f) \leq x)$ , where  $f$  is a parameter.

$f$	0.0005	0.001	0.005	0.01	0.025	0.05	0.10	0.20	0.30	0.40	0.50
1	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.15	0.27	0.45
2	0.00	0.00	0.01	0.02	0.05	0.10	0.21	0.45	0.71	1.02	1.39
3	0.02	0.02	0.07	0.11	0.22	0.35	0.58	1.01	1.42	1.87	2.37
4	0.06	0.09	0.21	0.30	0.48	0.71	1.06	1.65	2.19	2.75	3.36
5	0.16	0.21	0.41	0.55	0.83	1.15	1.61	2.34	3.00	3.66	4.35
6	0.30	0.38	0.68	0.87	1.24	1.64	2.20	3.07	3.83	4.57	5.35
7	0.48	0.60	0.99	1.24	1.69	2.17	2.73	3.62	4.67	5.49	6.35
8	0.71	0.86	1.34	1.65	2.18	2.73	3.49	4.59	5.53	6.42	7.34
9	0.97	1.15	1.73	2.09	2.70	3.33	4.17	5.38	6.39	7.36	8.34
10	1.26	1.48	2.16	2.56	3.25	3.94	4.87	6.18	7.27	8.30	9.34
11	1.59	1.83	2.60	3.05	3.82	4.57	5.58	6.99	8.15	9.24	10.34
12	1.93	2.21	3.07	3.57	4.40	5.23	6.30	7.81	9.03	10.18	11.34
13	2.31	2.62	3.57	4.11	5.01	5.89	7.04	8.63	9.93	11.13	12.34
14	2.70	3.04	4.07	4.66	5.63	6.57	7.79	9.47	10.82	12.08	13.34
15	3.11	3.48	4.60	5.23	6.26	7.26	8.55	10.31	11.72	13.03	14.34
16	3.54	3.94	5.14	5.81	6.91	7.96	9.31	11.15	12.62	13.98	15.34
17	3.98	4.42	5.70	6.41	7.56	8.67	10.09	12.00	13.53	14.94	16.34
18	4.44	4.90	6.26	7.01	8.23	9.39	10.86	12.86	14.44	15.89	17.34
19	4.91	5.41	6.84	7.63	8.91	10.12	11.65	13.72	15.35	16.85	18.34
20	5.40	5.92	7.43	8.26	9.59	10.85	12.44	14.58	16.27	17.81	19.34
21	5.90	6.45	8.03	8.90	10.28	11.59	13.24	15.44	17.18	18.77	20.34
22	6.40	6.98	8.64	9.54	10.98	12.34	14.04	16.31	18.10	19.73	21.34
23	6.92	7.53	9.26	10.20	11.69	13.09	14.85	17.19	19.02	20.69	22.34
24	7.45	8.08	9.89	10.86	12.40	13.85	15.66	18.06	19.94	21.65	23.34
25	7.99	8.65	10.52	11.52	13.12	14.61	16.47	18.94	20.87	22.62	24.34
26	8.54	9.22	11.16	12.20	13.84	15.38	17.29	19.82	21.79	23.58	25.34
27	9.09	9.80	11.81	12.88	14.57	16.15	18.11	20.70	22.72	24.54	26.34
28	9.66	10.39	12.46	13.56	15.31	16.93	18.94	21.59	23.65	25.51	27.34
29	10.23	10.99	13.12	14.26	16.05	17.71	19.77	22.48	24.58	26.48	28.34
30	10.80	11.59	13.79	14.95	16.79	18.49	20.60	23.36	25.51	27.44	29.34
40	16.91	17.92	20.71	22.16	24.43	26.51	29.05	32.34	34.87	37.13	39.34
50	23.46	24.67	27.99	29.71	32.36	34.76	37.69	41.45	46.86	51.62	59.33
60	30.34	31.74	35.53	37.48	40.48	43.19	46.46	50.64	53.81	56.62	59.33
100	59.90	61.92	67.33	70.06	74.22	77.93	82.36	87.95	92.13	95.81	99.33

Table for  $\chi^2(f)$  random variable  $F(x) = P(\chi^2(f) \leq x)$ , where  $f$  is a parameter.

$f$	0.60	0.70	0.80	0.90	0.95	0.975	0.99	0.995	0.999	0.9995
1	0.71	1.07	1.64	2.71	3.84	5.02	6.63	7.88	10.83	12.12
2	1.83	2.41	3.22	4.61	5.99	7.38	9.21	10.60	13.82	15.20
3	2.95	3.66	4.64	6.25	7.81	9.35	11.34	12.84	16.27	17.73
4	4.04	4.88	5.99	7.78	9.49	11.14	13.28	14.86	18.47	20.01
5	5.13	6.06	7.29	9.24	11.07	12.83	15.09	16.75	20.52	22.11
6	6.21	7.23	8.56	10.64	12.59	14.45	16.81	18.55	22.46	24.10
7	7.28	8.38	9.80	12.02	14.07	16.01	18.48	20.28	24.32	26.02
8	8.35	9.52	11.03	13.36	15.51	17.53	20.09	21.95	26.12	27.87
9	9.41	10.66	12.24	14.68	16.92	19.02	21.67	23.59	27.88	29.67
10	10.47	11.78	13.44	15.99	18.31	20.48	23.21	25.19	29.59	31.42
11	11.53	12.90	14.63	17.28	19.68	21.92	24.72	26.76	31.26	33.14
12	12.58	14.01	15.81	18.55	21.03	23.34	26.22	28.30	32.91	34.82
13	13.64	15.12	16.98	19.81	22.36	24.74	27.69	29.82	34.53	36.48
14	14.69	16.22	18.15	21.06	23.68	26.12	29.14	31.32	36.12	38.11
15	15.73	17.32	19.31	22.31	25.00	27.49	30.58	32.80	37.70	39.72
16	16.78	18.42	20.47	23.54	26.30	28.85	32.00	34.27	39.25	41.31
17	17.82	19.51	21.61	24.77	27.59	30.19	33.41	35.72	40.79	42.88
18	18.87	20.60	22.76	25.99	28.87	31.53	34.81	37.16	42.31	44.43
19	19.91	21.69	23.90	27.20	30.14	32.85	36.19	38.58	43.82	45.97
20	20.95	22.77	25.04	28.41	31.41	34.17	37.57	40.00	45.31	47.50
21	21.99	23.86	26.17	29.62	32.67	35.48	38.93	41.40	46.80	49.01
22	23.03	24.94	27.30	30.81	33.92	36.78	40.29	42.80	48.27	50.51
23	24.07	26.02	28.43	32.01	35.17	38.08	41.64	44.18	49.73	52.00
24	25.11	27.10	29.55	33.20	36.42	39.36	42.98	45.56	51.18	53.48
25	26.14	28.17	30.68	34.38	37.65	40.65	44.31	46.93	52.62	54.95
26	27.18	29.25	31.79	35.56	38.89	41.92	45.64	48.29	54.05	56.41
27	28.21	30.32	32.91	36.74	40.11	43.19	46.96	49.64	55.48	57.86
28	29.25	31.39	34.03	37.92	41.34	44.46	48.28	50.99	56.89	59.30
29	30.28	32.46	35.14	39.09	42.56	45.72	49.59	52.34	58.30	60.73
30	31.32	33.53	36.25	40.26	43.77	46.98	50.89	53.67	59.70	62.16
40	41.62	44.16	47.27	51.81	55.76	59.34	63.69	66.77	73.40	76.09
50	51.89	54.72	58.16	63.17	67.50	71.42	79.49	79.49	86.66	89.56
60	62.13	65.23	68.97	74.40	79.08	83.30	88.38	91.95	99.61	102.69
100	102.95	106.91	111.67	118.50	124.34	129.56	135.81	140.17	149.45	153.17



(9.4) Table for Binomial random variable  $P(Bin(n, p) \leq k)$  if  $p \leq 0.5$ .  
 If  $p > 0.5$ , then  $P(Bin(n, p) \leq k) = P(Bin(n, 1 - p) \geq n - k)$ .

$n$	$k$	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
2	0	0.9025	0.8100	0.7225	0.6400	0.5625	0.4900	0.4225	0.3600	0.3025	0.2500
	1	0.9975	0.9900	0.9775	0.9600	0.9375	0.9100	0.8775	0.8400	0.7975	0.7500
3	0	0.8574	0.7290	0.6141	0.5120	0.4219	0.3430	0.2746	0.2160	0.1664	0.1250
	1	0.9928	0.9720	0.9392	0.8960	0.8438	0.7840	0.7183	0.6480	0.5747	0.5000
4	0	0.8145	0.6561	0.5220	0.4096	0.3164	0.2401	0.1785	0.1256	0.0915	0.0625
	1	0.9860	0.9477	0.8905	0.8192	0.7383	0.6517	0.5630	0.4735	0.3910	0.3125
5	0	0.7738	0.5905	0.4437	0.3277	0.2373	0.1681	0.1160	0.0778	0.0503	0.0313
	1	0.9774	0.9185	0.8352	0.7373	0.6328	0.5282	0.4284	0.3370	0.2562	0.1875
6	0	0.7351	0.5314	0.3771	0.2621	0.1780	0.1176	0.0754	0.0467	0.0277	0.0156
	1	0.9672	0.8847	0.7765	0.6554	0.5339	0.4202	0.3191	0.2333	0.1636	0.1094
7	0	0.6983	0.4783	0.3206	0.2097	0.1335	0.0824	0.0490	0.0280	0.0152	0.0078
	1	0.9566	0.8503	0.7166	0.5767	0.4449	0.3294	0.2338	0.1586	0.1024	0.0625
8	0	0.6634	0.4305	0.2725	0.1678	0.1001	0.0576	0.0319	0.0168	0.0084	0.0039
	1	0.9428	0.8131	0.6572	0.5033	0.3671	0.2553	0.1691	0.1064	0.0632	0.0352
9	0	0.6302	0.3874	0.2316	0.1342	0.0751	0.0404	0.0207	0.0101	0.0046	0.0020
	1	0.9288	0.7748	0.5995	0.4362	0.3003	0.1960	0.1211	0.0705	0.0385	0.0195

Table for Binomial random variable  $P(Bin(n, p) \leq k)$  if  $p \leq 0.5$ .  
 If  $p > 0.5$ , then  $P(Bin(n, p) \leq k) = P(Bin(n, 1 - p) \geq n - k)$ .

$n$	$k$	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
10	0	0.5987	0.3487	0.1969	0.1074	0.0563	0.0282	0.0135	0.0060	0.0025	0.0010
	1	0.9139	0.7361	0.5443	0.3758	0.2440	0.1493	0.0860	0.0464	0.0233	0.0107
11	0	0.5688	0.3138	0.1673	0.0859	0.0422	0.0198	0.0088	0.0036	0.0014	0.0005
	1	0.8981	0.6974	0.4922	0.3221	0.1971	0.1130	0.0606	0.0302	0.0139	0.0059
12	0	0.5404	0.2824	0.1422	0.0687	0.0317	0.0138	0.0057	0.0022	0.0008	0.0002
	1	0.8816	0.6590	0.4435	0.2749	0.1584	0.0850	0.0424	0.0196	0.0083	0.0032

Table for Binomial random variable  $P(Bin(n, p) \leq k)$  if  $p \leq 0.5$ .  
 If  $p > 0.5$ , then  $P(Bin(n, p) \leq k) = P(Bin(n, 1 - p) \geq n - k)$ .

$n$	$k$	$p$														
		0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50					
14	0	0.4877	0.2288	0.1028	0.0440	0.0178	0.0068	0.0024	0.0008	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
	1	0.8470	0.5846	0.3567	0.2075	0.1010	0.0475	0.0205	0.0081	0.0029	0.0009	0.0001	0.0000	0.0000	0.0000	0.0000
	2	0.9699	0.8416	0.6479	0.4481	0.2811	0.1608	0.0839	0.0398	0.0170	0.0065	0.0016	0.0001	0.0000	0.0000	0.0000
	3	0.9958	0.9559	0.8535	0.6982	0.5213	0.3552	0.2205	0.1243	0.0632	0.0287	0.0116	0.0034	0.0008	0.0001	0.0000
	4	0.9996	0.9908	0.9533	0.8702	0.7415	0.5842	0.4227	0.2793	0.1672	0.0898	0.0427	0.0191	0.0065	0.0018	0.0003
	5	1.0000	0.9985	0.9885	0.9561	0.8883	0.7805	0.6405	0.4859	0.3373	0.2120	0.1200	0.0653	0.0319	0.0141	0.0054
	6	1.0000	0.9998	0.9978	0.9884	0.9617	0.9067	0.8164	0.6925	0.5461	0.3953	0.2500	0.1450	0.0780	0.0400	0.0180
	7	1.0000	1.0000	0.9997	0.9976	0.9897	0.9685	0.9247	0.8499	0.7414	0.6047	0.4600	0.3150	0.1900	0.1000	0.0500
	8	1.0000	1.0000	1.0000	0.9996	0.9978	0.9917	0.9757	0.9417	0.8811	0.7880	0.6700	0.5300	0.4000	0.2800	0.1800
	9	1.0000	1.0000	1.0000	1.0000	0.9998	0.9977	0.9933	0.9878	0.9744	0.9412	0.9102	0.8600	0.7800	0.6800	0.5800
	10	1.0000	1.0000	1.0000	1.0000	1.0000	0.9998	0.9989	0.9961	0.9886	0.9713	0.9400	0.9000	0.8300	0.7400	0.6400
	11	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9994	0.9978	0.9935	0.9850	0.9700	0.9450	0.9100	0.8600
	12	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9997	0.9991	0.9980	0.9960	0.9930	0.9880	0.9810
	13	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
15	0	0.4633	0.2059	0.0874	0.0352	0.0134	0.0047	0.0016	0.0005	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	1	0.8290	0.5490	0.3186	0.1671	0.0802	0.0353	0.0142	0.0052	0.0017	0.0005	0.0001	0.0000	0.0000	0.0000	0.0000
	2	0.9638	0.8159	0.6042	0.3980	0.2361	0.1268	0.0617	0.0271	0.0107	0.0037	0.0007	0.0001	0.0000	0.0000	0.0000
	3	0.9945	0.9444	0.8227	0.6482	0.4613	0.2969	0.1727	0.0905	0.0424	0.0176	0.0052	0.0014	0.0001	0.0000	0.0000
	4	0.9994	0.9873	0.9383	0.8338	0.6865	0.5155	0.3519	0.2173	0.1204	0.0592	0.0250	0.0100	0.0030	0.0005	0.0000
	5	0.9999	0.9978	0.9832	0.9389	0.8516	0.7216	0.5816	0.4303	0.2608	0.1509	0.0800	0.0400	0.0180	0.0070	0.0020
	6	1.0000	0.9997	0.9964	0.9819	0.9434	0.8689	0.7548	0.6098	0.4522	0.3036	0.1800	0.1000	0.0500	0.0250	0.0100
	7	1.0000	1.0000	0.9994	0.9958	0.9827	0.9500	0.8868	0.7869	0.6535	0.5000	0.3400	0.2000	0.1100	0.0550	0.0250
	8	1.0000	1.0000	0.9999	0.9992	0.9958	0.9848	0.9578	0.9050	0.8182	0.6964	0.5400	0.3800	0.2200	0.1200	0.0600
	9	1.0000	1.0000	1.0000	0.9999	0.9999	0.9992	0.9921	0.9231	0.8491	0.7400	0.6000	0.4300	0.2600	0.1400	0.0700
	10	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9993	0.9972	0.9907	0.9745	0.9400	0.8900	0.8200	0.7400	0.6500
	11	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9993	0.9981	0.9937	0.9824	0.9600	0.9300	0.8900	0.8300
	12	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9997	0.9989	0.9963	0.9890	0.9790	0.9650	0.9450	0.9200
	13	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999	0.9999
	14	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	16	0	0.4401	0.1853	0.0743	0.0281	0.0100	0.0033	0.0010	0.0003	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
1		0.8108	0.5147	0.2839	0.1407	0.0635	0.0261	0.0098	0.0033	0.0010	0.0003	0.0001	0.0000	0.0000	0.0000	0.0000
2		0.9571	0.7892	0.5614	0.3518	0.1971	0.0994	0.0451	0.0183	0.0066	0.0021	0.0004	0.0001	0.0000	0.0000	0.0000
3		0.9930	0.9316	0.7899	0.5981	0.4050	0.2459	0.1339	0.0651	0.0281	0.0106	0.0030	0.0008	0.0001	0.0000	0.0000
4		0.9991	0.9830	0.9209	0.7982	0.6302	0.4499	0.2892	0.1666	0.0853	0.0384	0.0150	0.0040	0.0010	0.0000	0.0000
5		0.9999	0.9967	0.9765	0.9183	0.8103	0.6598	0.4900	0.3288	0.1976	0.1051	0.0500	0.0200	0.0080	0.0020	0.0000
6		1.0000	0.9995	0.9944	0.9733	0.9204	0.8247	0.6881	0.5272	0.3660	0.2272	0.1300	0.0700	0.0350	0.0150	0.0050
7		1.0000	0.9999	0.9989	0.9930	0.9729	0.9236	0.8406	0.7161	0.5629	0.4018	0.2500	0.1400	0.0750	0.0350	0.0150
8		1.0000	1.0000	0.9998	0.9985	0.9925	0.9743	0.9329	0.8577	0.7441	0.5982	0.4300	0.2600	0.1400	0.0700	0.0300
9		1.0000	1.0000	1.0000	0.9998	0.9988	0.9925	0.9711	0.9417	0.8759	0.7728	0.6400	0.4500	0.2600	0.1400	0.0600
10		1.0000	1.0000	1.0000	1.0000	0.9997	0.9984	0.9984	0.9997	0.9951	0.9849	0.9600	0.9200	0.8500	0.7500	0.6300
11		1.0000	1.0000	1.0000	1.0000	1.0000	0.9997	0.9987	0.9951	0.9851	0.9616	0.9200	0.8500	0.7500	0.6300	0.5000
12		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9998	0.9991	0.9965	0.9894	0.9779	0.9550	0.9200	0.8600	0.7700
13		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9994	0.9994	0.9979	0.9940	0.9870	0.9770	0.9650
14		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9997	0.9997	0.9997	0.9997	0.9997
15		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table for Binomial random variable  $P(Bin(n, p) \leq k)$  if  $p \leq 0.5$ .  
 If  $p > 0.5$ , then  $P(Bin(n, p) \leq k) = P(Bin(n, 1 - p) \geq n - k)$ .

$n$	$k$	$p$														
		0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50					
17	0	0.4181	0.1668	0.0631	0.0225	0.0075	0.0023	0.0007	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	1	0.7922	0.4818	0.2525	0.1182	0.0501	0.0193	0.0067	0.0021	0.0006	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
	2	0.9497	0.7618	0.5198	0.3096	0.1637	0.0774	0.0327	0.0123	0.0041	0.0012	0.0001	0.0000	0.0000	0.0000	0.0000
	3	0.9912	0.9174	0.7556	0.5489	0.3530	0.2019	0.1028	0.0464	0.0184	0.0064	0.0014	0.0001	0.0000	0.0000	0.0000
	4	0.9988	0.9779	0.9013	0.7582	0.5739	0.3887	0.2348	0.1260	0.0596	0.0245	0.0094	0.0024	0.0001	0.0000	0.0000
	5	0.9999	0.9953	0.9681	0.8943	0.7653	0.5668	0.4197	0.2639	0.1471	0.0717	0.0280	0.0100	0.0030	0.0001	0.0000
	6	1.0000	0.9992	0.9922	0.9623	0.8929	0.7752	0.6188	0.4478	0.2902	0.1622	0.0800	0.0350	0.0120	0.0040	0.0001
	7	1.0000	0.9999	0.9983	0.9891	0.9823	0.9508	0.8954	0.7872	0.6405	0.4743	0.2900	0.1400	0.0600	0.0200	0.0050
	8	1.0000	1.0000	0.9997	0.9974	0.9876	0.9597	0.9006	0.8011	0.6626	0.5000	0.3400	0.1900	0.1000	0.0500	0.0200
	9	1.0000	1.0000	1.0000	0.9999	0.9995	0.9969	0.9873	0.9617	0.9081	0.8166	0.6855	0.5200	0.3500	0.1900	0.0900
	10	1.0000	1.0000	1.0000	1.0000	0.9999	0.9994	0.9969	0.9873	0.9617	0.9081	0.8166	0.6855	0.5200	0.3500	0.1900
	11	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9970	0.9894	0.9699	0.9283	0.8338	0.7000	0.5200	0.3200
	12	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9994	0.9975	0.9914	0.9755	0.9400	0.8600	0.7400	0.6000
	13	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9999	0.9981	0.9936	0.9836	0.9636	0.9336
	14	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	15	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	18	0	0.3972	0.1501	0.0536	0.0180	0.0056	0.0016	0.0004	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1		0.7735	0.4503	0.2241	0.0991	0.0395	0.0142	0.0046	0.0013	0.0003	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
2		0.9419	0.7338	0.4797	0.2713	0.1353	0.0600	0.0236	0.0082	0.0025	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000
3		0.9891	0.9018	0.7202	0.5010	0.3057	0.1646	0.0783	0.0328	0.0120	0.0038	0.0008	0.0001	0.0000	0.0000	0.0000
4		0.9985	0.9718	0.8794	0.7164	0.5187	0.3327	0.1886	0.0942	0.0411	0.0154	0.0040	0.0005	0.0000	0.0000	0.0000
5		0.9998	0.9936	0.9351	0.8671											

(9.5) Table for Poisson random variable  $P(Po(\mu) \leq k)$ .

$k$	$\mu$									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.9048	0.8187	0.7408	0.6703	0.6065	0.5488	0.4966	0.4493	0.4066	0.3679
1	0.9953	0.9825	0.9631	0.9384	0.9098	0.8781	0.8442	0.8088	0.7725	0.7358
2	0.9998	0.9989	0.9964	0.9921	0.9856	0.9769	0.9659	0.9526	0.9371	0.9197
3	1.0000	0.9999	0.9997	0.9992	0.9982	0.9966	0.9942	0.9909	0.9865	0.9810
4	1.0000	1.0000	1.0000	0.9999	0.9998	0.9996	0.9992	0.9986	0.9977	0.9963
5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9998	0.9997	0.9994
6	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999
7	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
$k$	$\mu$									
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
0	0.3329	0.3012	0.2725	0.2466	0.2231	0.2019	0.1827	0.1653	0.1496	0.1353
1	0.6990	0.6626	0.6268	0.5918	0.5578	0.5249	0.4932	0.4628	0.4337	0.4060
2	0.9004	0.8795	0.8571	0.8335	0.8088	0.7834	0.7572	0.7306	0.7037	0.6767
3	0.9743	0.9662	0.9569	0.9463	0.9344	0.9212	0.9068	0.8913	0.8747	0.8571
4	0.9946	0.9923	0.9893	0.9857	0.9814	0.9763	0.9704	0.9636	0.9559	0.9473
5	0.9990	0.9985	0.9978	0.9968	0.9955	0.9940	0.9920	0.9896	0.9868	0.9834
6	0.9999	0.9997	0.9996	0.9994	0.9991	0.9987	0.9981	0.9974	0.9966	0.9955
7	1.0000	1.0000	0.9999	0.9999	0.9998	0.9997	0.9996	0.9994	0.9992	0.9989
8	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9999	0.9998
9	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
$k$	$\mu$									
	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0
0	0.1225	0.1108	0.1003	0.0907	0.0821	0.0743	0.0672	0.0608	0.0550	0.0498
1	0.3796	0.3546	0.3309	0.3084	0.2873	0.2674	0.2487	0.2311	0.2146	0.1991
2	0.6496	0.6227	0.5960	0.5697	0.5438	0.5184	0.4936	0.4695	0.4460	0.4232
3	0.8386	0.8194	0.7993	0.7787	0.7576	0.7360	0.7141	0.6919	0.6696	0.6472
4	0.9379	0.9275	0.9162	0.9041	0.8912	0.8774	0.8629	0.8477	0.8318	0.8153
5	0.9796	0.9751	0.9700	0.9643	0.9580	0.9510	0.9433	0.9349	0.9258	0.9161
6	0.9941	0.9925	0.9906	0.9884	0.9858	0.9828	0.9794	0.9756	0.9713	0.9665
7	0.9985	0.9980	0.9974	0.9967	0.9958	0.9947	0.9934	0.9919	0.9901	0.9881
8	0.9997	0.9995	0.9994	0.9991	0.9989	0.9985	0.9981	0.9976	0.9969	0.9962
9	0.9999	0.9999	0.9999	0.9998	0.9997	0.9996	0.9995	0.9993	0.9991	0.9989
10	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9999	0.9998	0.9997	0.9996
11	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9999
12	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table for Poisson random variable  $P(Po(\mu) \leq k)$ .

$k$	$\mu$									
	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0
0	0.0408	0.0334	0.0273	0.0224	0.0183	0.0150	0.0123	0.0101	0.0082	0.0067
1	0.1712	0.1468	0.1257	0.1074	0.0916	0.0780	0.0663	0.0563	0.0477	0.0404
2	0.3799	0.3397	0.3027	0.2689	0.2381	0.2102	0.1851	0.1626	0.1425	0.1247
3	0.6025	0.5584	0.5152	0.4735	0.4335	0.3954	0.3594	0.3257	0.2942	0.2650
4	0.7806	0.7442	0.7064	0.6678	0.6288	0.5898	0.5512	0.5132	0.4763	0.4405
5	0.8946	0.8705	0.8441	0.8156	0.7851	0.7531	0.7199	0.6858	0.6510	0.6160
6	0.9534	0.9421	0.9267	0.9091	0.8893	0.8675	0.8436	0.8180	0.7908	0.7622
7	0.9832	0.9769	0.9682	0.9599	0.9509	0.9419	0.9321	0.9214	0.9049	0.8866
8	0.9943	0.9917	0.9883	0.9840	0.9786	0.9721	0.9642	0.9549	0.9442	0.9319
9	0.9982	0.9973	0.9960	0.9942	0.9919	0.9889	0.9851	0.9805	0.9749	0.9682
10	0.9995	0.9992	0.9987	0.9981	0.9972	0.9959	0.9943	0.9922	0.9896	0.9863
11	0.9999	0.9998	0.9996	0.9994	0.9991	0.9986	0.9980	0.9971	0.9960	0.9945
12	1.0000	0.9999	0.9999	0.9999	0.9998	0.9997	0.9996	0.9993	0.9990	0.9986
13	1.0000	1.0000	1.0000	1.0000	0.9999	0.9997	0.9996	0.9993	0.9990	0.9986
14	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9998	0.9997	0.9995
15	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9998
$k$	$\mu$									
	5.2	5.4	5.6	5.8	6.0	6.5	7.0	7.5	8.0	8.5
0	0.0055	0.0045	0.0037	0.0030	0.0025	0.0015	0.0009	0.0006	0.0003	0.0002
1	0.0342	0.0289	0.0244	0.0206	0.0174	0.0113	0.0073	0.0047	0.0030	0.0019
2	0.1088	0.0948	0.0824	0.0715	0.0620	0.0430	0.0286	0.0203	0.0138	0.0093
3	0.2381	0.2133	0.1906	0.1700	0.1512	0.1118	0.0818	0.0591	0.0424	0.0301
4	0.4061	0.3733	0.3422	0.3127	0.2851	0.2237	0.1730	0.1321	0.0996	0.0744
5	0.5809	0.5461	0.5119	0.4783	0.4457	0.3690	0.3007	0.2414	0.1912	0.1496
6	0.7324	0.7017	0.6703	0.6384	0.6063	0.5265	0.4497	0.3782	0.3134	0.2562
7	0.8449	0.8217	0.7970	0.7710	0.7440	0.6728	0.5987	0.5246	0.4530	0.3856
8	0.9181	0.9027	0.8857	0.8672	0.8472	0.7916	0.7291	0.6620	0.5925	0.5231
9	0.9603	0.9512	0.9409	0.9292	0.9161	0.8774	0.8305	0.7764	0.7166	0.6530
10	0.9823	0.9775	0.9718	0.9651	0.9574	0.9332	0.9015	0.8622	0.8159	0.7634
11	0.9927	0.9904	0.9875	0.9841	0.9799	0.9661	0.9467	0.9208	0.8881	0.8487
12	0.9972	0.9962	0.9949	0.9932	0.9912	0.9840	0.9730	0.9573	0.9362	0.9091
13	0.9990	0.9986	0.9980	0.9973	0.9964	0.9929	0.9872	0.9784	0.9658	0.9486
14	0.9999	0.9995	0.9993	0.9990	0.9986	0.9970	0.9943	0.9897	0.9827	0.9726
15	0.9999	0.9998	0.9998	0.9996	0.9995	0.9988	0.9976	0.9954	0.9918	0.9862
16	1.0000	0.9999	0.9999	0.9999	0.9998	0.9996	0.9990	0.9980	0.9963	0.9934
17	1.0000	1.0000	1.0000	1.0000	0.9999	0.9998	0.9996	0.9992	0.9984	0.9970
18	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9997	0.9993	0.9987
19	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9997	0.9995
20	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9998
21	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999
22	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table for Poisson random variable  $P(Po(\mu) \leq k)$ .

$k$	$\mu$																
	9.0	9.5	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0							
0	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000							
1	0.0012	0.0008	0.0005	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000							
2	0.0062	0.0042	0.0028	0.0012	0.0005	0.0002	0.0001	0.0000	0.0000	0.0000							
3	0.0212	0.0149	0.0103	0.0049	0.0023	0.0011	0.0005	0.0002	0.0001	0.0000							
4	0.0550	0.0403	0.0293	0.0151	0.0076	0.0037	0.0018	0.0009	0.0004	0.0002							
5	0.1157	0.0885	0.0671	0.0375	0.0203	0.0107	0.0055	0.0028	0.0014	0.0007							
6	0.2068	0.1649	0.1301	0.0786	0.0458	0.0259	0.0142	0.0076	0.0040	0.0021							
7	0.3239	0.2687	0.2202	0.1432	0.0895	0.0540	0.0316	0.0180	0.0100	0.0054							
8	0.4557	0.3918	0.3328	0.2320	0.1550	0.0998	0.0621	0.0374	0.0220	0.0126							
9	0.5874	0.5218	0.4579	0.3405	0.2424	0.1658	0.1094	0.0699	0.0433	0.0261							
10	0.7060	0.6453	0.5830	0.4599	0.3472	0.2517	0.1757	0.1185	0.0774	0.0491							
11	0.8030	0.7520	0.6968	0.5793	0.4616	0.3532	0.2600	0.1848	0.1270	0.0847							
12	0.8758	0.8364	0.7916	0.6887	0.5760	0.4631	0.3585	0.2676	0.1931	0.1350							
13	0.9261	0.8981	0.8645	0.7813	0.6815	0.5730	0.4644	0.3632	0.2745	0.2009							
14	0.9585	0.9400	0.9165	0.8540	0.7720	0.6751	0.5704	0.4657	0.3675	0.2808							
15	0.9780	0.9665	0.9513	0.9074	0.8444	0.7636	0.6694	0.5681	0.4667	0.3715							
16	0.9889	0.9823	0.9730	0.9441	0.8987	0.8355	0.7559	0.6641	0.5660	0.4677							
17	0.9947	0.9911	0.9857	0.9678	0.9370	0.8905	0.8272	0.7489	0.6593	0.5640							
18	0.9976	0.9957	0.9928	0.9823	0.9626	0.9302	0.8826	0.8195	0.7423	0.6550							
19	0.9989	0.9980	0.9965	0.9907	0.9787	0.9573	0.9235	0.8752	0.8122	0.7363							
20	0.9996	0.9991	0.9984	0.9953	0.9884	0.9750	0.9521	0.9170	0.8682	0.8055							
21	0.9998	0.9996	0.9993	0.9977	0.9939	0.9859	0.9712	0.9469	0.9108	0.8615							
22	0.9999	0.9999	0.9997	0.9990	0.9970	0.9924	0.9833	0.9673	0.9418	0.9047							
23	1.0000	0.9999	0.9999	0.9995	0.9985	0.9960	0.9907	0.9805	0.9633	0.9367							
24	1.0000	1.0000	1.0000	0.9998	0.9993	0.9980	0.9950	0.9888	0.9777	0.9594							
25	1.0000	1.0000	1.0000	0.9999	0.9997	0.9990	0.9974	0.9938	0.9869	0.9748							
26	1.0000	1.0000	1.0000	1.0000	0.9999	0.9995	0.9987	0.9967	0.9925	0.9848							
27	1.0000	1.0000	1.0000	1.0000	0.9999	0.9998	0.9994	0.9983	0.9959	0.9912							
28	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9997	0.9991	0.9978	0.9950							
29	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9996	0.9994	0.9986							
30	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9997	0.9993							
31	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9997	0.9996							
32	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9996							
33	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999	0.9999	0.9999							
34	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999							
35	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000							