Application of Derivatives

- For a quantity y varying with another quantity x, satisfying the rule $y = f(x)$, the rate of change of y with respect to x is given by $\frac{dy}{dx}$ or $f'(x)$

  The rate of change of y with respect to x at the point $x = x_0$ is given by $\left.\frac{dy}{dx}\right]_{x=x_0}$ or $f'(x_0)$.

- If the variables x and y are expressed in form of $x = f(t)$ and $y = g(t)$, then the rate of change of y with respect to x is given by $\frac{dy}{dx} = \frac{g'(t)}{f'(t)}$ provided $f'(t) \neq 0$

a. A function f: $(a, b) \rightarrow \mathbf{R}$ is said to be

- increasing on (a, b), if $x_1 < x_2$ in (a, b)
- decreasing on (a, b), if $x_1 < x_2$ in (a, b)

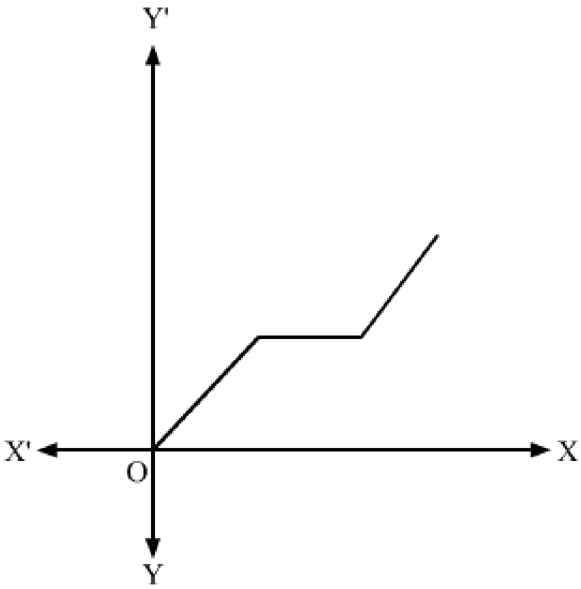
OR

If a function f is continuous on $[a, b]$ and differentiable on (a, b), then

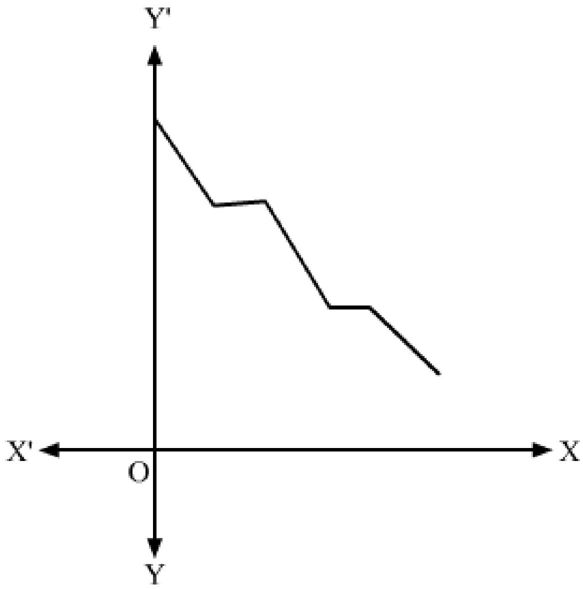
- f is increasing in $[a, b]$, if $f'(x) > 0$ for each xÎ (a, b)
- f is decreasing in$[a, b]$, if $f'(x) < 0$ for each xÎ (a, b)
- f is constant function in $[a, b]$, if $f'(x) = 0$ for each xÎ (a, b)

a. A function f: (a, b) ® **R** is said to be
   - strictly increasing on (a, b), if $x_1 < x_2$ in (a, b) Þ $f(x_1) < f(x_2)$ " x_1, x_2 Î (a, b)
   - strictly decreasing on (a, b), if $x_1 < x_2$ in (a, b) Þ $f(x_1) > f(x_2)$ " x_1, x_2 Î (a, b)

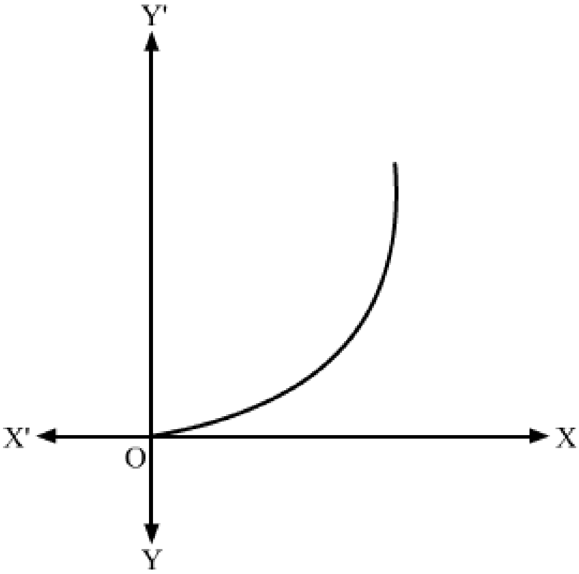
   a. The graphs of various types of functions can be shown as follows:



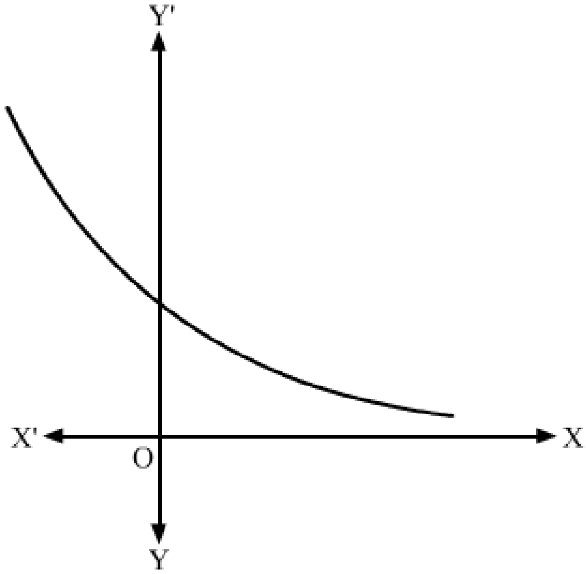
Increasing Function



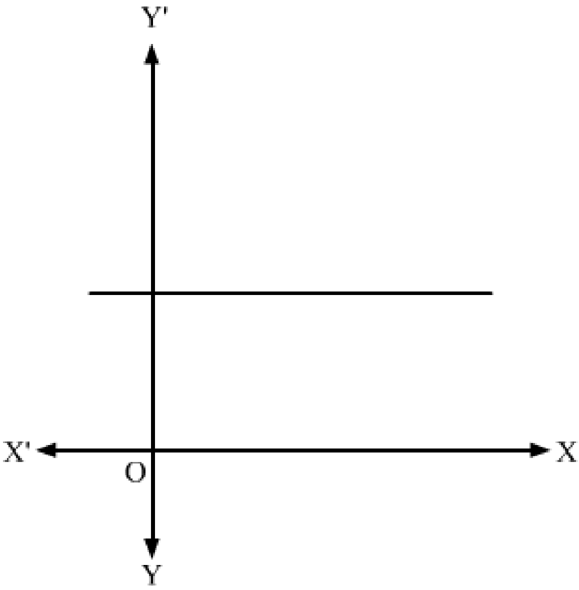
Decreasing Function



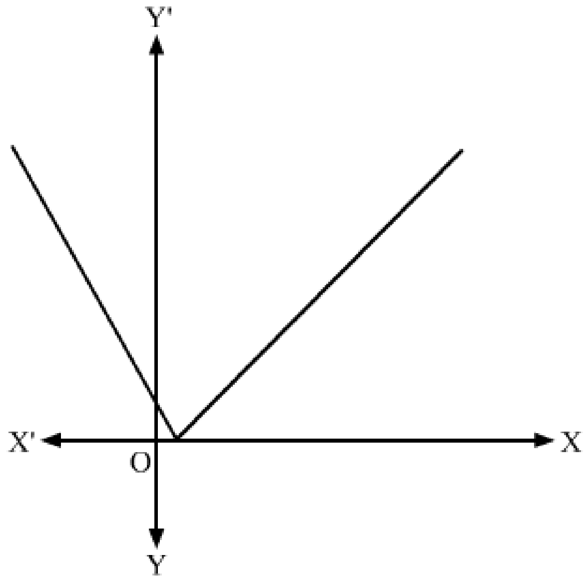
Strictly Increasing Function



Strictly Decreasing Function



Constant Function



Neither increasing or dreasing function

Example 1: Find the intervals in which the function *f* given by $f(x) = \sqrt{3}\sin x - \cos x, x \in [0,\ 2\pi]$ is strictly increasing or decreasing.

Solution:

$f(x) = \sqrt{3}\sin x - \cos x$

$\therefore f'(x) = \sqrt{3}\cos x + \sin x$

$f'(x) = 0 \text{ gives } \tan x = -\sqrt{3}$

$\therefore x = \frac{2\pi}{3},\ \frac{5\pi}{3}$

The points $x = \frac{2\pi}{3}$ and $x = \frac{5\pi}{3}$ divide the interval [0, 2π] into three disjoint intervals, $\left[0,\ \frac{2\pi}{3}\right),\ \left(\frac{2\pi}{3},\ \frac{5\pi}{3}\right),\ \left(\frac{5\pi}{3},\ 2\pi\right]$.

Now, $f'(x) > 0, \text{ if } x \in \left[0, \frac{2\pi}{3}\right) \cup \left(\frac{5\pi}{3}, 2\pi\right]$

f is strictly increasing in the intervals $\left[0, \frac{2\pi}{3}\right) \text{ and } \left(\frac{5\pi}{3}, 2\pi\right]$.

Also, $f'(x) < 0, \text{ if } x \in \left(\frac{2\pi}{3}, \frac{5\pi}{3}\right)$

f is strictly decreasing in the interval $\left(\frac{2\pi}{3}, \frac{5\pi}{3}\right)$.

- For the curve $y = f(x)$, the slope of tangent at the point (x_0, y_0) is given by $\left.\frac{dy}{dx}\right]_{(x_0, y_0)}$ or $f'(x_0)$.
- For the curve $y = f(x)$, the slope of normal at the point (x_0, y_0) is given by $\frac{-1}{\left.\frac{dy}{dx}\right]_{(x_0, y_0)}}$ or $\frac{-1}{f'(x_0)}$.
- The equation of tangent to the curve $y = f(x)$ at the point (x_0, y_0) is given by, $y - y_0 = f'(x_0) \times (x - x_0)$
- If $f'(x_0)$ does not exist, then the tangent to the curve $y = f(x)$ at the point (x_0, y_0) is parallel to the *y*-axis and its equation is given by $x = x_0$.
- The equation of normal to the curve $y = f(x)$ at the point (x_0, y_0) is given by, $y - y_0 = \frac{-1}{f'(x_0)}\left(x - x_0\right)$
- If $f'(x_0)$ does not exist, then the normal to the curve $y = f(x)$ at the point (x_0, y_0) is parallel to the *x*-axis and its equation is given by $y = y_0$.
- If $f'(x_0) = 0$, then the respective equations of the tangent and normal to the curve $y = f(x)$ at the point (x_0, y_0) are $y = y_0$ and $x = x_0$.

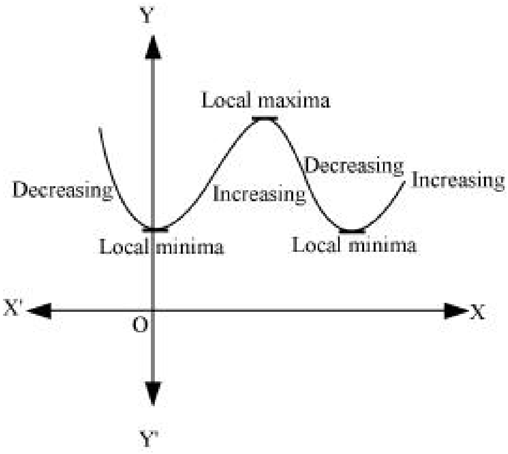
- Let $y = f(x)$ and let Δx be a small increment in *x* and Δy be the increment in *y* corresponding to the increment in *x* i.e., $\Delta y = f(x + \Delta x) - f(x)$

Then, $dy = f'\left(x\right)dx$ or $dy = \left(\frac{dy}{dx}\right)\Delta x$ is a good approximation of Δy, when $dx = \Delta x$ is relatively small and we denote it by $dy \approx \Delta y$.

- **Maxima and Minima**: Let a function *f* be defined on an interval I. Then, *f* is said to have
  - maximum value in I, if there exists $c \in$ I such that $f(c) > f(x)$, $\forall\ x \in$ I [In this case, *c* is called the point of maxima]
  - minimum value in I, if there exists $c \in$ I such that $f(c) < f(x)$, $\forall\ x \in$ I [In this case, *c* is called the point of minima]
  - an extreme value in I, if there exists $c \in$ I such that *c* is either point of maxima or point of minima [In this case, *c* is called an extreme point]

Note: Every continuous function on a closed interval has a maximum and a minimum value.

- **Local maxima and local minima:** Let *f* be a real-valued function and *c* be an interior point in the domain of *f*. Then, *c* is called a point of
  - local maxima, if there exists $h > 0$ such that $f(c) > f(x)$, $\forall\ x \in (c - h, c + h)$ [In this case, $f(c)$ is called the local maximum value of *f*]
  - local minima, if there exists $h > 0$ such that $f(c) < f(x)$, $\forall\ x \in (c - h, c + h)$ [In this case, $f(c)$ is called the local maximum value of *f*]



- A point *c* in the domain of a function *f* at which either $f'(c) = 0$ or *f* is not differentiable is called a critical point of *f*.

- **First derivative test:** Let *f* be a function defined on an open interval I. Let *f* be continuous at a critical point *c* in I. Then:
  - If $f'(x)$ changes sign from positive to negative as *x* increases through *c*, i.e. if $f'(x) > 0$ at every point sufficiently close to and to the left of *c*, and $f'(x) < 0$ at every point sufficiently close to and to the right of *c*, then *c* is a point of local maxima.
  - If $f'(x)$ changes sign from negative to positive as *x* increases through *c*, i.e. if $f'(x) < 0$ at every point sufficiently close to and to the left of *c*, and $f'(x) > 0$ at every point sufficiently close to and to the right of *c*, then *c* is a point of local minima.
  - If $f'(x)$ does not change sign as *x* increases through *c*, then *c* is neither a point of local maxima nor a point of local minima. Such a point *c* is called point of inflection.

- **Second derivative test:** Let *f* be a function defined on an open interval I and $c \in$ I. Let *f* be twice differentiable at *c* and $f'(c) = 0$ Then:
  - If $f''(c) < 0$, then *c* is a point of local maxima. In this situation, *f*(*c*) is local maximum value of *f*.
  - If $f''(c) > 0$, then *c* is a point of local minima. In this situation, *f*(*c*) is local minimum value of *f*.
  - If $f''(c) = 0$, then the test fails. In this situation, we follow first derivative test and find whether *c* is a point of maxima or minima or a point of inflection.

Example 1: Find all the points of local maxima or local minima of the function *f* given by $f(x) = x^3 - 12x^2 + 36x - 4$.

Solution:
We have,

$$f(x) = x^3 - 12x^2 + 36x - 4$$

$$\therefore f'(x) = 3x^2 - 24x + 36 = 3\left(x^2 - 8x + 12\right)$$

$$\text{and } f''(x) = 3(2x - 8) = 6(x - 4)$$

$$\text{Now, } f'(x) = 0 \text{ gives } x^2 - 8x + 12 = 0$$

$$\Rightarrow (x-2)(x-6) = 0$$

$$\Rightarrow x = 2 \text{ or } x = 6$$

$$\text{However, } f''(2) = -12 \text{ and } f''(6) = 12$$

Therefore, the point of local maxima and local minima are at the points $x = 2$ and $x = 6$ respectively.
The local maximum value is $f(2) = 28$
The local minimum value is $f(6) = -4$