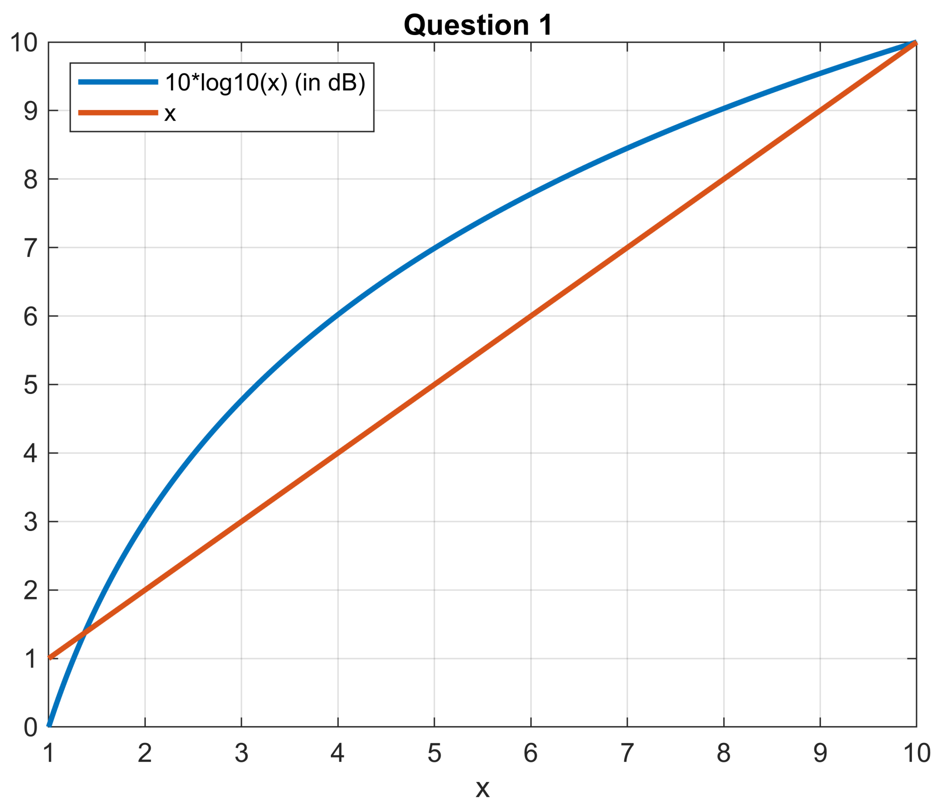
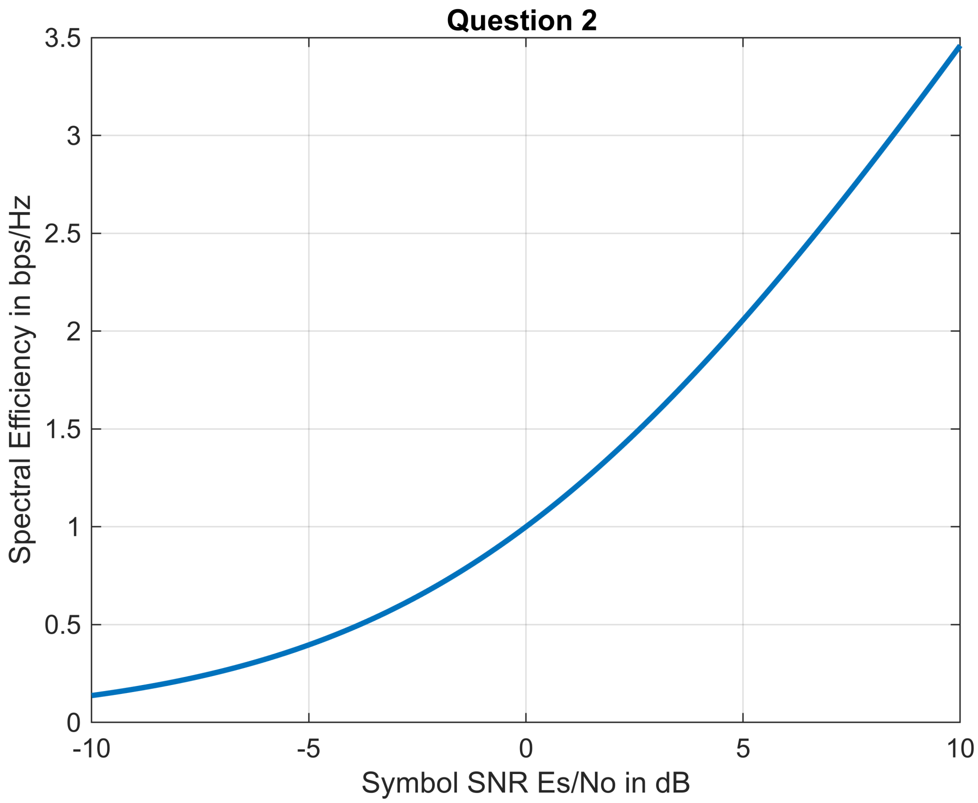
```
%Question 1

x = 1:0.01:10;
y = 10 * log10(x);
plot(x, y,'LineWidth',2);
hold on;
plot(x, x,'LineWidth',2);
legend({'10*log10(x) (in dB)', 'x'}, 'Location', 'NorthWest');
xlabel('x');
grid on;
title('Question 1 ');
```



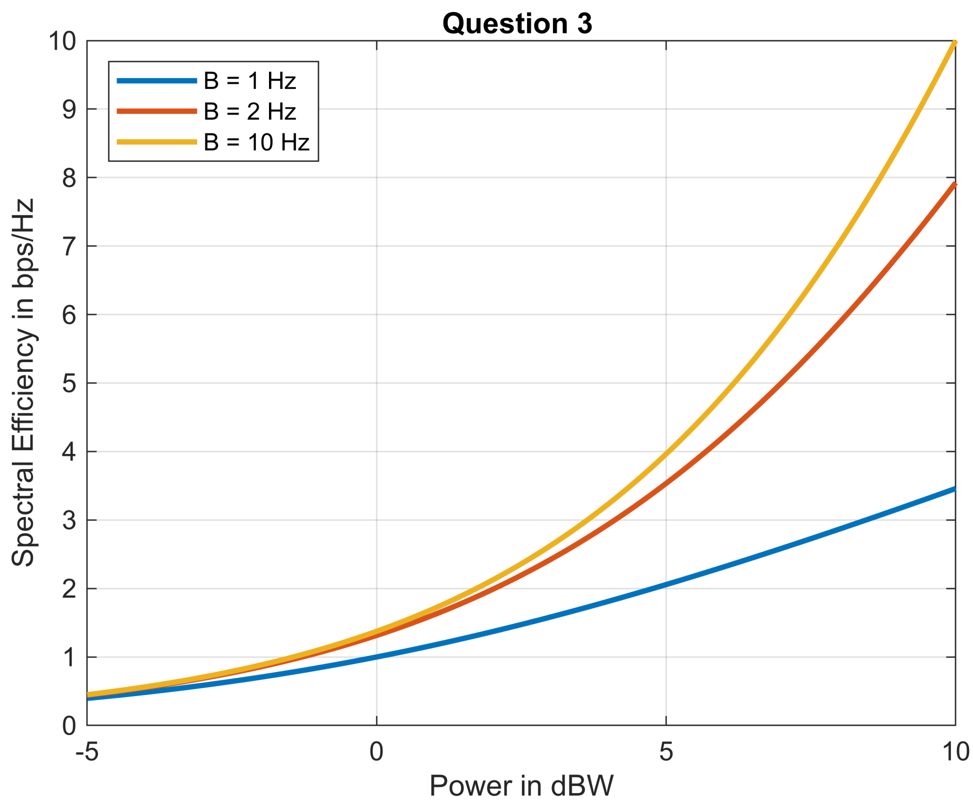

```
%Question 2

figure;
x=-10:0.1:10;
z = 10.^(x/10);
y = log2(1+z);
plot(x,y,'LineWidth',2);
xlabel('Symbol SNR Es/No in dB');
ylabel('Spectral Efficiency in bps/Hz');
grid on;
title('Question 2 ');
```




```
%{
(a)The mismatch we see is that when lambda -> 0 the value for eta_b on the graph is
1 but in our analysis, we got the value for eta_b as 0.
The reason for this mismatch is the graph we plotted is in linear scale whereas the
values of lambda are in decibel scale.
One way to remove this mismatch is to plot the graph against a logarithmic scale.
%}

%For reference of the above the code goes like:-
%x=-10:0.1:10;
%z = 10.^(x/10);
%y = log2(1+z);
%plot(z,y,'LineWidth',2);
%xlabel('Symbol SNR Es/No in dB');
%ylabel('Spectral Efficiency in bps/Hz');
%grid on;
%title('Question 2 z y ');
```

```
%Question 3
```

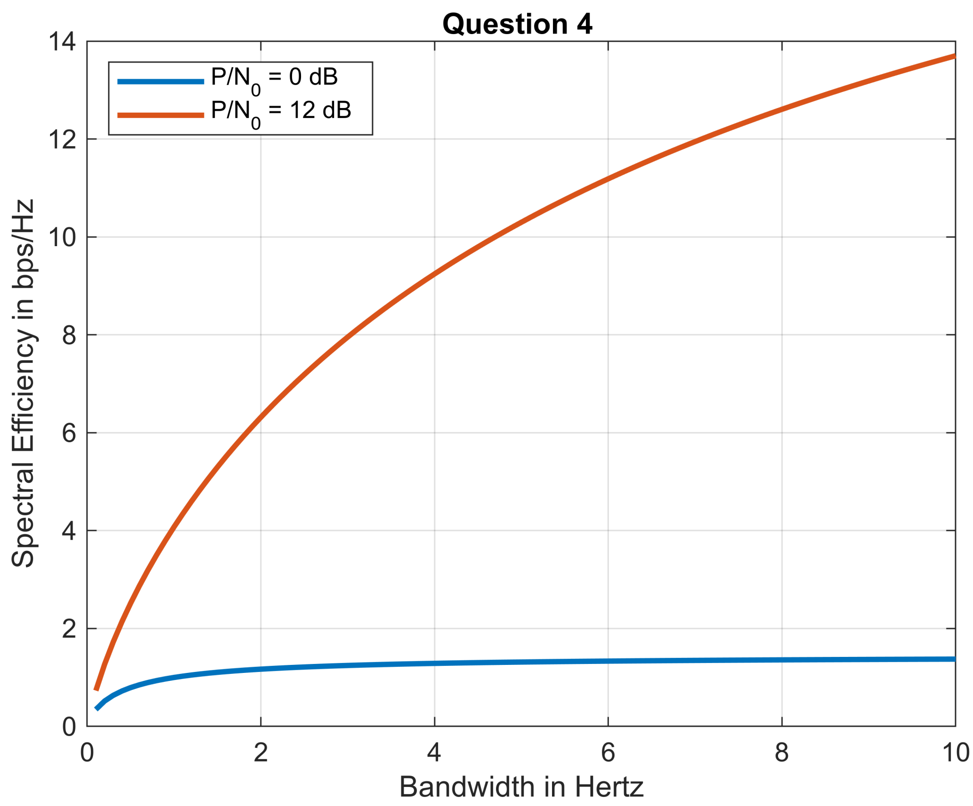
```
figure;
Ps = -5:0.1:10;
B=1;
Pslinear=10.^(Ps/10);
C=B*log2(1+Pslinear./B);
plot(Ps,C,'LineWidth',2);
hold on;
B=5;
Pslinear=10.^(Ps/10);
C=B*log2(1+Pslinear./B);
plot(Ps,C,'LineWidth',2);
hold on;
B=10;
Pslinear=10.^(Ps/10);
C=B*log2(1+Pslinear./B);
plot(Ps,C,'LineWidth',2);
legend({'B = 1 Hz','B = 2 Hz', 'B = 10 Hz'}, 'Location', 'NorthWest');
xlabel('Power in dBW');
ylabel('Spectral Efficiency in bps/Hz');
grid on;
title('Question 3 ');
```




```
%{
The graph between eta_b and power looks similar to the graph between eta_b because
both the graphs are plotting the same equation with a different scale.
```

```
Since both the variations of eta_b are derived from the same equation : Shannon's
Channel Capacity Equation.
%}
```

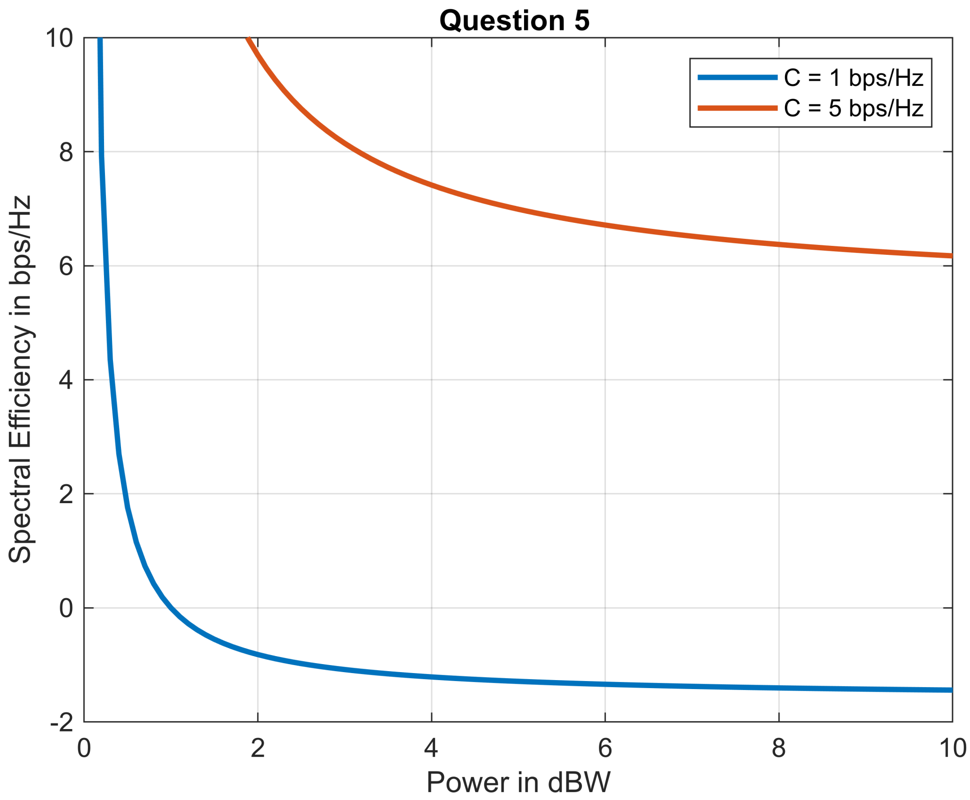
```
%Question 4

figure;
B = 0:0.1:10;
Ps = 0;
Ps = 10.^(Ps./10);
C = B.*(log2(1+(Ps)./B));
plot(B,C,'LineWidth',2);
hold on;
Ps = 12;
Ps = 10.^(Ps./10);
C = B.*(log2(1+(Ps)./B));
plot(B,C,'LineWidth',2);
legend({'P/N_0 = 0 dB','P/N_0 = 12 dB'}, 'Location', 'NorthWest');
xlabel('Bandwidth in Hertz');
ylabel('Spectral Efficiency in bps/Hz');
grid on;
title('Question 4 ');
```




```
%{
```

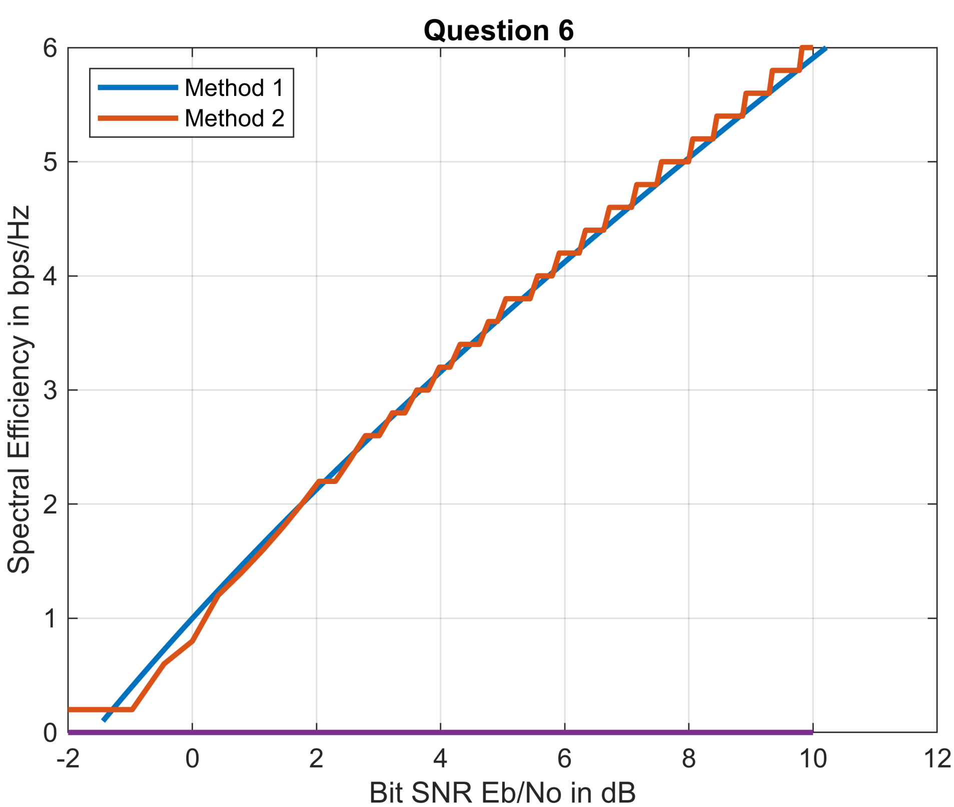
```
The graph shows us how channel capacity varies with B for some fixed received power
level. This fixed value of data rate/ channel capacity is different with different
values of B
In the case of P/N_0 = 0dB, the limiting value is around 1.44 which is in agreement
with our analytical answer in 4(b) which is 1/ln(2) = 1/(0.69) = 1.44
%}
```

```
%Question 5

figure;
B=0:0.1:10;
C=1;
Ps = ((2.^(C./B))-1).*B;
Ps = 10*log10(Ps);
ylim([-2 10]);
plot(B,Ps,'LineWidth',2);
C=5;
hold on;
Ps = ((2.^(C./B))-1).*B;
Ps = 10*log10(Ps);
ylim([-2 10]);
plot(B,Ps,'LineWidth',2);
legend({'C = 1 bps/Hz','C = 5 bps/Hz'});
xlabel('Power in dBW');
ylabel('Spectral Efficiency in bps/Hz');
grid on;
title('Question 5 ');
```




```
%Question 6
%Method 1

figure;
nb=0:0.1:6;

ratio=((2.^nb)-1)./(nb);
ratio = 10.*log10(ratio);
plot(ratio,nb,'LineWidth',2);
hold on;
xaxis = 0:0.1:10;

yaxis = 0:0.2:6;
val = zeros(length(xaxis));
tolerance=0.1;
for i = 1:length(xaxis)
    left = 1;
    right = length(yaxis);

    while left <= right
        mid = floor((left + right) / 2);
        x = yaxis(mid);
        alpha = (2^x - 1) / x;

        if alpha >= xaxis(i)
```

```
            val(i) = x;
            right = mid - 1;
        else
            if (xaxis(i)-alpha)<=tolerance
               val(i)=x;
               break;
            end
            left = mid + 1;
        end
    end
end

plot(10.*log10(xaxis), val,'LineWidth',2);
xlim([-2,12]);
legend({'Method 1','Method 2'}, 'Location', 'NorthWest');
xlabel('Bit SNR Eb/No in dB');
ylabel('Spectral Efficiency in bps/Hz');
grid on;
title('Question 6 ');
```




```
%{
The value of E_b/N_0 when eta_B becomes zero is -1.59 in dB which is equal to the
analytical answer ln(2) in linear scale.

We get the analytical answer by finding lim eta_b->0 (2^eta_b -1)/eta_b and getting
value for E_b/N_0
```

```
(L'Hospital Rule)
%}
```

Introduction to
Communication
Systems

* Analysis Exercises

1. $1W \rightarrow 10^3 mW (x)$

$x_d = 10\log_{10}(x)$

$x_d = 10\log_{10}(10^3) = 30 dBm$

Now:

10dBm power in W

$\therefore 10 = 10\log_{10}(x)$

$\boxed{x = 10mW = 0.01W}$

2. Small - SNR → ~~[illegible]~~ λ very small

Large - SNR → λ ~~very~~ large

$\eta_B = \log_2(1+\lambda)$

Small SNR ⇒ $\eta_B = \log_2(1+\lambda) \cong \lambda$

Large SNR ⇒ $\eta_B = \log_2(1+\lambda) \cong \log_2(\lambda)$

- SNR = k (fixed)

→ $\eta_B = \log_2(1+\lambda)$

$= \log_2(1+k)$

$\eta_B = const. = \frac{R_b}{B}$ | $R_b = cB \Rightarrow \boxed{R_b \propto B \text{ Linearly}}$

Teacher's Signature:...................

4. (a) SNR or $\lambda = \frac{E_s}{N_o}$ $\frac{P_s}{N_o} = K(\text{fixed})$, as $B \to \infty$

$\lambda = \frac{E_s}{N_o} = \frac{P_s}{P_N}$ & $P_N = N_o \times B$.

$\lambda = \frac{P_s}{N_o \cdot B} = \boxed{\frac{k}{B}}$, $\boxed{\text{as } B \to \infty}$

$\therefore \boxed{\lambda \to 0}$

(b) $R_B = \log_2(1+\lambda)$

$\lambda = \frac{P_s}{P_N}$

$R_B = B \log_2\left(1 + \frac{P_s}{N_o B}\right)$

$R_B = \log_2\left(1 + \frac{P_s}{N_o B}\right)^B$

As $\left(1 + \frac{P_s}{N_o B}\right)^B \Rightarrow 1^\infty$ Taking $\lim_{B \to \infty}$

$\therefore \lim_{B \to \infty}\left(1 + \frac{P_s}{N_o \cdot B}\right)^B \Rightarrow e^{P_s/N_o}$

$R_B = \frac{\log_e e^{P_s/N_o}}{\log_e 2} \Rightarrow \boxed{R_B = \frac{1}{\ln 2}\frac{P_s}{N_o}}$

5. (a) $(1+p) \longrightarrow 4p\ dB$ $1 \le (1+p) \le 1.25$.

$\boxed{0 \le p \le 0.25}$ -(i)

$x_d = 10\log_{10}(x)$

$\Rightarrow X_d = 10\log_{10}(1+p)$

$0 \le X_d \le 10\log_{10}(1.25)$

$0 \le X_d \le 0.9691$

as $10\log_{10}(1+p)$ is approximated as $4p$ in dB

$0 \le 4p \le 0.9691$ (dB)

$\boxed{0 \le p \le 0.24227}$ -(ii)

From (i) & (ii) we can say that they both are very close to each other $\therefore$ It is valid approx.

Teacher's Signature:

Also we can see this as $\rightarrow$ $4x \simeq 10\log_{10}(1+x)$ (through graph)

as we can see for very small value of x i.e. p (here) $4x$ & $10\log_{10}x$ are approx. same.

$4x \simeq 10\log_{10}(1+x)$

for $0 < x \leq 0.25$.

Hence a valid approx.

(b) As in quest^n $\rightarrow$ money is taken into considerat^n & dB based scaling is asked. So let us check what does doubling money mean in dB scale.

$10\log_{10}(x) = X_d$

$10\log_{10}(2x) = 10\log_{10}(2) + 10\log_{10}(x) = \underset{(\text{approx.})}{3} + X_d$

So to check as whether $(1+p) \rightarrow 4p$ dB corresponds to "75 Rule".

verification Compound Int. $\rightarrow$ $P\left(1+\frac{r}{100}\right)^t$ $\rightarrow$ Assuming this to be our i/p in eq.(10).

$$10\log_{10}\left(P\underbrace{\left(1+\frac{r}{100}\right)^t}_{1+p}\right) \simeq 4\left(\underbrace{2P\left(1+\frac{r}{100}\right)^t}_{\text{twice the money}} - 1\right)$$

let $P = 1$ ₹

$r = 5\%$ (as in Q.)

$\therefore 10\log_{10}(1.05)^t \simeq 4\left(2(1.05)^t - 1\right)$

If $t = 15$ yrs

$3.17 \simeq 12.63$

$\rightarrow$ $\therefore$ 12.63 is approx. equal to 4 times 3.17.

$\therefore$ $t = 15$ yrs at 5% rate is valid approx. which nearly corresponds to Rule of 75.

Teacher's Signature:..................

For doubling money at $r = 5\%$

$\frac{69.1244}{5} \approx 13.824$ yrs

(c) Using C.I. formula of t ($P = 1$ Rs) — t = time (yrs)

$P\left(1 + \frac{r}{n}\right)^{nt}$ — n is no. of times it gets compounded

$\therefore \lim_{n \to \infty} \left(1 + \frac{r}{n}\right)^{nt} \rightarrow 1^{\infty}$ form — (r is actually in $\frac{r}{100}$ form)

$\lim_{g \to \infty} f^{g} = \left| e^{g(f-1)} \right| \rightarrow e^{nt\left(\cancel{1+\frac{r}{n}-1}\right)}$ (Applying Lim)

e^{rt}

$r = 100\%$

$t = 1$ yr $\quad e^{\frac{100}{100}} = e$ $\therefore$ In comparison to e it is ~~[illegible]~~ equal to it

$P = 1$ Rs.

(d) $\cancel{P}\left(1 + \frac{r}{100}\right)^{t} = 2\cancel{P}$

$(1.05)^{t} = 2$

~~$t \approx 15$ yrs~~ Taking log

~~$t \log_{10}$~~ $\rightarrow t \log_{10}(1.05) = \log_{10} 2$

$t \approx 14.15$ yr

which was closest in the case of Rule of 72.

Teacher's Signature:..................