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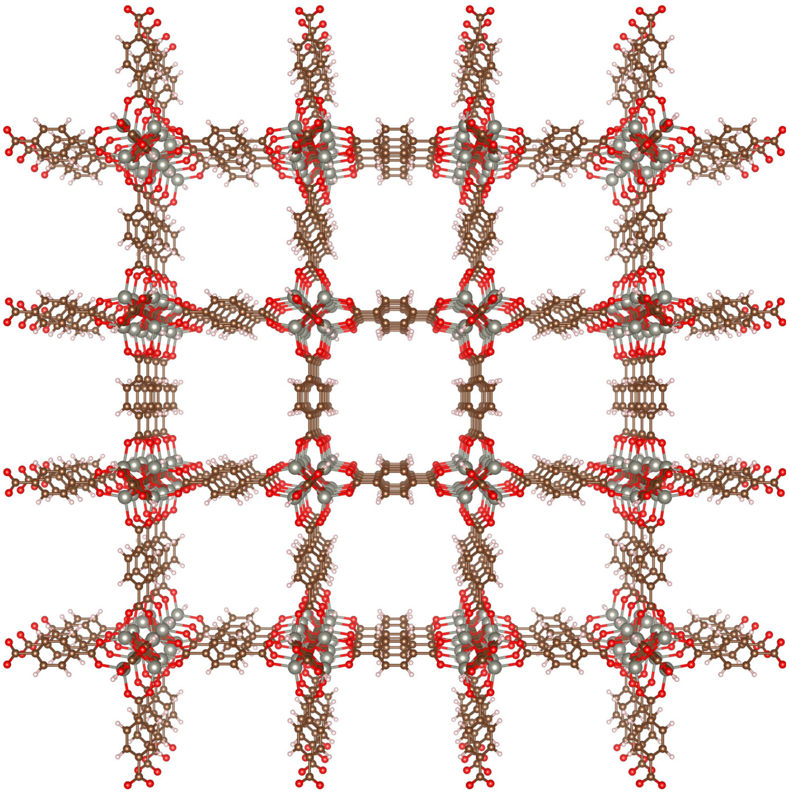

Department of Physics, Prithvi Narayan Campus, Pokhara
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Chief Editor

Aabiskar Bhusal

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Cover: Ball-and-stick model of MOF-5. © Roshani Sharma. Printed with permission.

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Himalayan Physics

Comparative study of solar flux using different empirical models at low land urban industrial zone of Biratnagar Nepal

Research Article

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Abstract: Nepal is a developing country in the world where sufficient clean energy is not available in our daily needs for cooking, lighting and other developmental activities. So, it is high time to promote clean and green energy, which is freely available in every corner of the country. In this regard, the present study helps to estimate the global solar radiation at the lowland region Biratnagar (lat. 26°28′53″N, long. 87°15′50″E and Alt. 72 m) using measured global solar radiation (GSR) and sunshine hours on empirical models. This paper uses the regression technique on two different empirical models Angstrom-Prescott(A-P) and Tiwari and Sangeeta, to estimate solar radiation. After analyzing the data on empirical models, the empirical constants 0.25 and 0.23 and 0.13 and 0.24 are found in A-P and Tiwari and Sangeeta models, respectively. The performance of the models was carried out by employing mean bias error (MBE), mean percentage error (MPE), root mean square error (RMSE) and adjusted coefficient of determination (R^2). These statistical tools reveal that all these models are statistically significant. Such a study is relevant when reliable data for solar radiation is not adequately available. The findings of empirical coefficients can be utilized for predicting solar radiation and solar energy at similar geographical locations in Nepal.

Keywords: Empirical coefficient • Global solar radiation • Linear models • Regression technique • Sunshine duration

I. Introduction

The world's ever-increasing population, the fast-depleting resources of fossil fuels and awareness of the environmental impact have led us to think about alternative sources of clean energy for the long-term existence of life on the Earth. Therefore, the world is looking for non-exhaustible and renewable energy sources which will save the world from tremendous crises. Among the other renewable energies, solar energy is one of the best alternatives since it is abundant, freely available and environment friendly [1]. The solar radiation falling on the earth's surface plays a vital role in changing physical, chemical and biological phenomena. Despite this crucial importance, in developing countries like Nepal, it is more difficult to measure solar irradiance in many parts

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of the country due to financial and technical constraints. Hence, developing different models and software to estimate solar radiation precisely is essential. The knowledge of Global Solar Radiation (GSR) is essential in the prediction, study and design of the economic viability of solar energy devices which uses solar energy. Information on GSR recorded at any site should be useful for the locality where radiation data is collected and the wider world community. The solar radiation data needs for designers and manufacturers of solar equipment [2].

Solar energy is vital in de-carbonizing the global economy, improving energy efficiency, and imposing costs on greenhouse gas emitters. The primary data on solar radiation are input in the case of solar energy applications such as photovoltaic, solar-thermal systems, solar furnaces and passive solar design. The GSR at any particular site is determined by installing measuring instruments such as a pyranometer and pyrheliometer at that place and recording the data daily. This work is more tedious and costly. Similarly, meteorological data are not available in many developing countries like Nepal. The main aim of this study is to estimate solar flux and, in the long run, to develop a solar map of Nepal. In addition, the predicted solar flux data helps researchers evaluate solar applications in Nepal [3].

Many researchers have developed monthly mean global solar radiation models using several approaches that include classical empirical regression, artificial neural networks (ANN), and autoregressive moving–average (ARMA) time–series regression techniques [4]. In 1924 Angstrom proposed the first theoretical model to estimate monthly mean global solar radiation on horizontal surfaces based on sunshine duration [5]. This equation is the simplest and most widely used. It is related to the monthly average daily radiation to clear day radiation in a given location and the average fraction of possible sunshine hours. Later in 1940, Prescott modified a formula of the Angstrom equation and focused on extraterrestrial radiation on a horizontal surface rather than on clear-day radiation. After that, many other models have been developed on the basis of the Angstrom-Prescott model by using meteorological, geographical and climatological parameters like relative humidity, cloudiness, latitude, altitude, air temperature, precipitation, and sunshine hours in order to estimate the monthly mean daily solar radiation of particular site [4]. Page provided the empirical coefficients of the modified Angstrom-type model, which has been claimed to be applicable in most parts of the world [6].

The concept of ANNs attracted much more interest in estimating GSR in distinct places worldwide in the last decade. Mellit applied an ANN for predicting solar radiation in terms of sunshine and ambient temperature in Algeria [7]. Yacef et al. developed new combined models utilizing a Bayesian neural network (BNN). The authors used maximum and minimum air temperatures to estimate GSR. They have proven that the newly calibrated models are able to estimate GSR with excellent accuracy in Algeria [8, 9]. Voyant et al. [10] proposed a paper to predict global solar radiation in five main Mediterranean places using a hybrid ARMA/ANN model and data from a numerical weather prediction model (ALADIN). The paper resulted that RMSE in the hybrid model is 14.9%, whereas that of the original ANN model is 18.4% .

Guclu et al. have proposed combining the harmonic and classical linear regression model called the HarLin model to forecast solar radiation in three Turkish locations. The results are tested and compared with that of the Adaptive-Neuro Fuzzy Inference System (ANFIS) model based on the Sugeno Fuzzy Logic inference system and Angstrom model. The predictions by the HarLin model have appeared to be more accurate than that of the ANFIS and classical Angstrom models [11–13]

The essence of this research is to develop models for estimating the total solar radiation for the selected location during 2014 and 2015 and compares the statistical results. The data used in the present study were obtained from the Department of Hydrology and Meteorology (DHM) in Kathmandu, Nepal. CMP6 Pyranometer is used for monitoring ground-based GSR.

II. Data and Methodology

Biratnagar is situated in the eastern part of Nepal at an altitude of 72 m with latitude. $26^\circ28'53''$N and longitude $87^\circ15'50''$E. It has a population of 214,663, according to the census of Nepal 2011 making it the biggest city in the eastern region. Biratnagar is a metropolitan city. This town is the capital of province one of Nepal. Its climate is warm and temperate. The average temperature of Biratnagar is 24.3°C annually. Its climate is extremely hot, up to 40°C, humid in summer, and very cold and foggy in winter. It is heavily suffered from cold waves in the winter season. It faces lots of rainfall in summer. The average rainfall is 1898 mm annually. December faces the least amount of rainfall. January is the coldest month in Biratnagar with a temperature of 12.9°C [14, 15]. The study site is shown below in Fig. 1.

This research aims to study and predict solar radiation using two empirical models Angstrom-Prescott (A-P) and Tiwari & Sangeeta, with meteorological parameters used over the Biratnagar. The secondary data is taken by the Department of Hydrology and Meteorology (DHM), Government of Nepal, by using CMP6 Pyranometer on a daily basis. The GSR for 2015 is predicted by using empirical constants derived from the models used for 2014. Here, the statistical tools are used to test the error that occurred in this study. The monthly and seasonal variation in GSR is also studied.

Selection of Models

There are many empirical models developed in order to estimate global solar radiation. Sunshine-based models such as the Modified Angstrom and Tiwari and Sangeeta models are selected to study the solar flux at Biratnagar, Nepal. The basic explanation of these models is explained below.

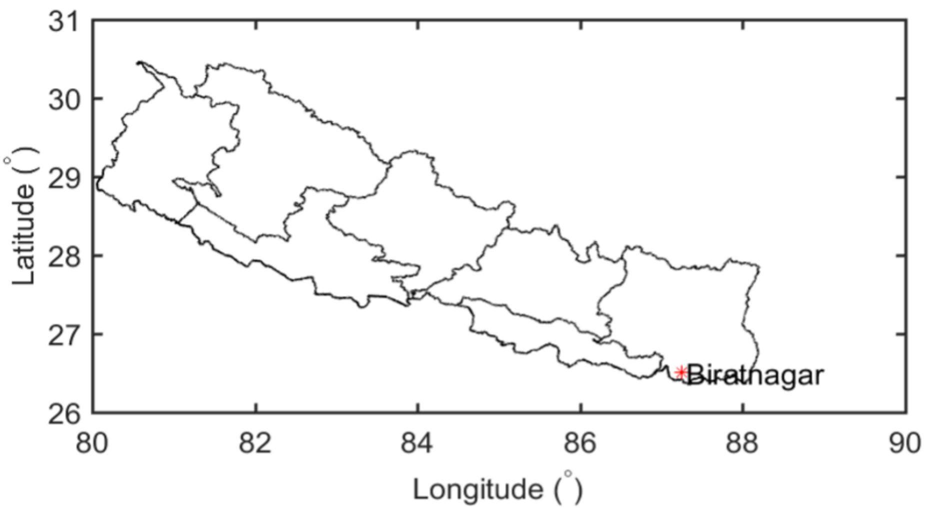

Figure 1. Location of Biratnagar on the map of Nepal [16].

Angstrom – Prescott model

$$\frac{H_g}{H_0} = a + b\left(\frac{s}{S_0}\right) \tag{1}$$

where H_g is the monthly average global solar radiation on a horizontal surface $\left(MJ^2/m^2/day\right)$, H_0 is the monthly average daily extraterrestrial radiation on a horizontal surface $\left(MJ/m^2/day\right)$, the monthly average daily hours of bright sunshine, S_0 the monthly average day length and “a” and “b” values are known as empirical constants. However, equation (1) is termed as first order and linear. Here, H_0 can be calculated from the following equation.

$$H_0 = \left(\frac{24}{\pi}\right) I_{gc}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]\left[\cos\emptyset\cos\delta\sin w_a + \left(\frac{2\pi w_s}{360}\right)\sin\emptyset\sin\delta\right] \tag{2}$$

where, I_{s6} is the solar constant $\left(1367\ W/m^2\right)$, is the site’s latitude, $w_{s\ t}$ the mean sunrise hour angle for a given month, δ the solar declination and n is the number of the year starting from January. Here, the solar declination (δ) and the mean sunrise hour angle (W_s) can be calculated by the following equations (3), respectively [17].

$$\begin{aligned} \delta &= 23.45\sin\left[\frac{360(284+n)}{365}\right]\ldots \\ w_2 &= \cos^{-1}(-\tan\emptyset\tan\delta) \end{aligned} \tag{3}$$

The monthly average day length (s_0) can be computed by using the following equation.

$$s_0 = \frac{2}{15} w_s \tag{4}$$

Hence, we can estimate the solar radiation potential of a location by obtaining values of regression constants and sunshine duration [18].

Tiwari and Sangeeta model

In this model, the regression coefficients "a" and "b" can be calculated by using Tiwari and Sangeeta's model given by:

$$\begin{aligned} a &= -0.110 + 0.235 \cos\phi + 0.323 \left(\frac{s}{s_0}\right) \\ b &= 1.449 - 0.553 \cos\phi - 0.694 \left(\frac{s}{s_0}\right) \end{aligned} \tag{5}$$

III. Results and Discussion

In this study, the meteorological data are computed, and empirical coefficients are reported by using the selected empirical models with the help of the regression technique method. Using these coefficients, we estimated the solar flux values in Biratnagar for 2014 and 2015.

Monthly mean variation of GSR

The monthly mean measured value of GSR is shown in Fig. 2(a) for the year 2014 in Biratnagar. GSR's maximum and minimum value is observed to be 14.81 and 7.59MJ/m^2/day in March and December, respectively. The annual average measured value of GSR was 11.36MJ/m^2/ day for 2014. The coefficient of determination and p-values are obtained as 0.92 and 0.012 , respectively. It indicates that about 92 percent of the data is closer to the best-fit line. The trend line of the sixth-degree polynomial is fitted with measured data of GSR in Biratnagar and is shown in Fig. 2(a).

Similarly, the monthly mean measured value of GSR is shown in Fig. 2(b) for 2015 in Biratnagar. The maximum and minimum value of GSR is observed to be 12.48 and 8.69 MJ/m^2/day in April and January, respectively. The annual average measured value of GSR was 12.48 MJ/m^2/day for 2015. The coefficient of determination and p-values are obtained as 0.85 and 0.05, respectively. It indicates that about 85 percent of the data is closer to the best-fit line. The trend line of a sixth-degree polynomial is fitted with measured data of GSR in Biratnagar and is shown in Fig. 2(b).

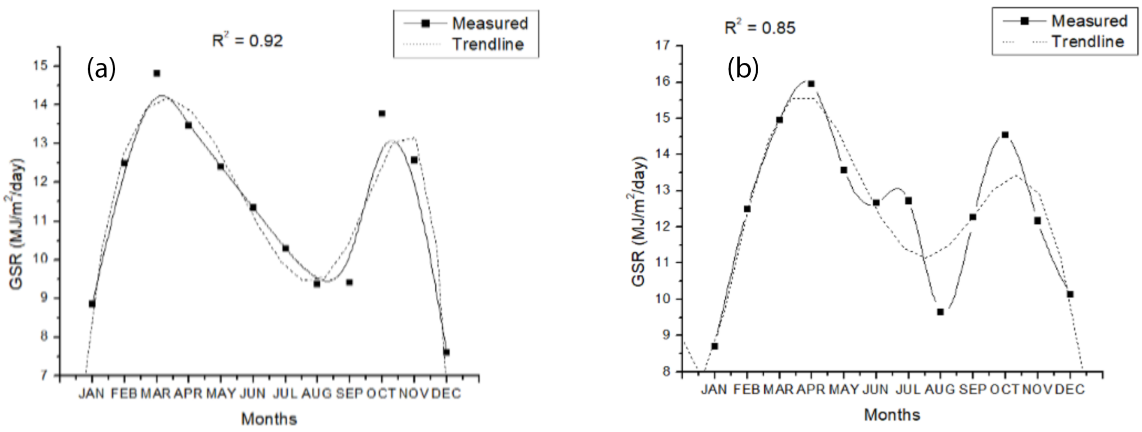

Figure 2. Monthly mean variations of GSR in Biratnagar for the year (a) 2014 and (b) 2015.

Seasonal variation of GSR

The Seasonal variation of GSR for winter (December, January, February), spring (March, April, May), summer (June, July, August) and autumn (September, October, November) is computed from the data for the years 2014 and 2015. The average measured values of GSR for winter, spring, summer, and autumn are 9.67, 13.56, 10.32 and 11.92 MJ/m^2/day, respectively, for the year 2014. Similarly, for the year 2015, the average measured values of GSR are observed to be 10.58, 14.83, 11.67 and 12.99 (MJ/m^2/day) for winter, spring, summer and autumn, respectively.

The seasonal variations of GSR in Biratnagar are presented in Fig. 3(a) and Fig. 3(b) for the years 2014 and 2015, respectively. The figure shows error bars for each season with a 5% confidence level. The error is obtained more in spring than in others.

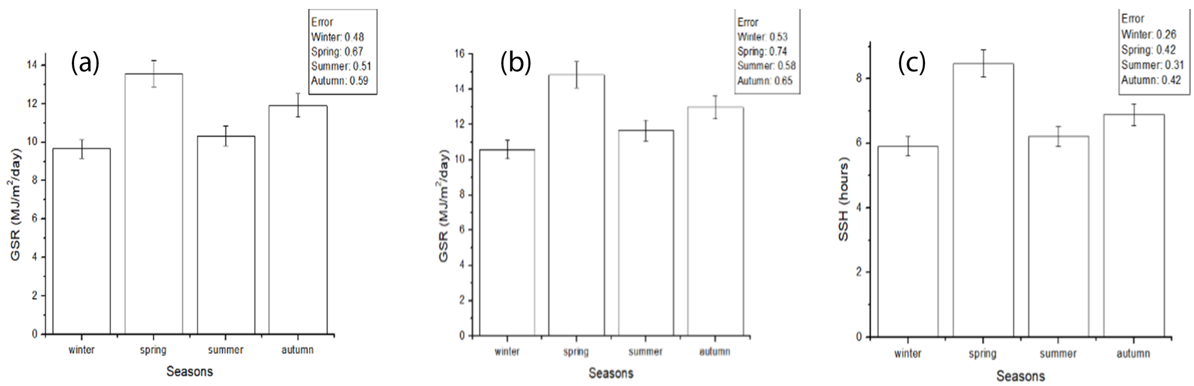

Figure 3. Seasonal variation of GSR in Biratnagar for the year (a) 2014 and (b) 2015. (c) Average seasonal variations of the sunshine hour (SSH) in Biratnagar for the years 2014 and 2015

There are many factors that affect the seasonal variation of GSR; among them, sunshine hour (SSH) is one of the main factors. When the sunshine hour increases, the GSR of the site also increases. The average value of sunshine hour (SSH) is observed to be 5.91, 8.46, 6.31 and 6.88 hours for winter, spring, summer and autumn, respectively. The annual average global solar radiation in Biratnagar is 11.92 MJ/m^2/day between 2014 and 2015. Fig. 3(c) represents the average sunshine hour (SSH) in Biratnagar for the years 2014 and 2015.

A study of both years' data shows that the maximum and minimum values of GSR in Biratnagar are spring and winter, respectively. Also, SSH is found to be maximum in spring and minimum in winter. The maximum value of GSR in spring occurs due to long average sunshine hours, low precipitation, less cloudiness and less solar zenith angle during this season. But the low value of GSR is attributed to more solar zenith angles, the appearance of foggy days, severe cold waves, and haze, and the distance between the earth and the sun is shortest in January. But the solar zenith angle is larger during this period since the sun lies in the southern hemisphere. Although we feel hot on summer days, the GSR value is relatively lower than in spring. In general, the monsoon begins in mid-June and ends at the beginning of September in Nepal. The rainfall in Nepal is due to the monsoon in summer. Hence, the heavy rain and cloudiness reduce the average GSR in Biratnagar.

Estimation of GSR using sunshine based models

In this study, two models viz. Angstrom-Prescott Model and Tiwari and Sangeeta Models are used to predict GSR in Biratnagar using two years of meteorological data (2014/2015). Using the regression technique, the empirical coefficients corresponding to the selected models are shown in Table 1 below:

Table 1. Average value of the empirical coefficients of the selected models for the years 2014 and 2015.

S.N.	Models	Empirical Coefficients	
		a	b
1.	Angstrom-Prescott (Linear)	0.25	0.23
2.	Tiwari and Sangeeta	0.13	0.24

Now, the modified form of linear A-P models is given below:

$$\frac{H_g}{H_0} = 0.25 + 0.23\left(\frac{s}{S_0}\right) \tag{6}$$

Then, monthly average daily global solar radiations are estimated with the help modified empirical model (equation (6)) by using measured SSH, monthly average daily extraterrestrial solar radiation and day length in Biratnagar for the years 2014 and 2015. The corresponding average errors that occur for the models used are shown in Table 2.

Table 2. The average statistical error for the years 2014 and 2015.

S.N.	Models	MBE	MPE(%)	RMSE
1.	Angstrom-Prescott (Linear)	-0.05	0.093	0.30
2.	Tiwari and Sangeeta	8.25	25.74	11.23

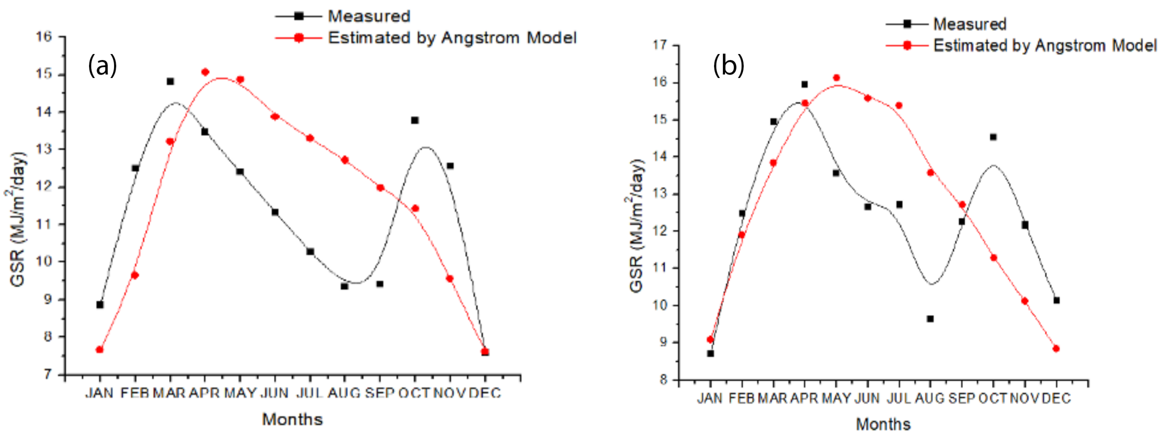

Figure 4. Comparison between measured and estimated GSR of Biratnagar using Linear A-P model for the year (a) 2014 and (b) 2015.

The performance of the estimated GSR is statistically compared with measured GSR data. The values of mean bias error (MBE), mean percentage error (MPE)and root mean square error (RMSE) range from -0.05, 0.093 and 0.30 and 8.25, 25.74, 0.23 and 11.23, respectively, for A-P model and Tiwari and Sangeeta models respectively. The values of the RMSE in Biratnagar are relatively higher than those of MBE and MPE. However, it provides information on the short-term performance of a correction. MBE's positive and negative values signify over-estimation and under-estimation in calculation values, respectively. The above statistical tests signify that the estimated GSR is nearly closer to the measured GSR. From Table 1, the sum of empirical constants ("a" and "b") obtained from the Linear A-P model is larger (0.48) than that of the Tiwari & Sangeeta model (0.37). Similarly, the sum is higher for the Linear A-P model than Tiwari and Sangeeta's models used in Table 2. This gives information that the Linear Angstrom Model is best for estimating GSR. Now, the measured value of the monthly average daily global solar radiation (H_{meas}) is compared with the estimated value of the monthly average daily global solar radiation (H_{est}) for the years 2014 and 2015 both.

IV. Conclusions

The overall performance of the A-P model is better than Tiwari and Sangeeta models. Its empirical coefficients, a and b, are 0.25 and 0.23, respectively. Finally, the finding empirical coefficients are used to predict the solar flux and solar energy in a similar climatic zone of Nepal.

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The authors are grateful to sincerely thank the Department of Hydrology and Meteorology (DHM), Government of Nepal, for providing the meteorological data. We would like to convey special thanks to faculty members and staff of the Department of Applied Sciences and Chemical Engineering, IOE, Pulchowk Campus, Tribhuvan University and Department of Physics, Patan Multiple Campus, TU, Patan Dhoka.

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