Calculation total mass stopping power (Collision and Radiation) for electrons in Semiconductor compound (ZnO) within low and medium energies

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Abstract
Charged particles interact with matter in several methods, one these method is Stopping Power .
In this research we have calculated total mass stopping power using [Bethe – Block] equations, in Semiconductor Compound ZnO. within the range of energy (0.1 – 9) MeV .
The total mass stopping power include from two types of interactions, the first called collision stopping power ($-dE/dx)_{col}$, and the Second radiation stopping power $(-dE/dx)_{rad}$. the collision stopping power calculated using Bethe equation , and the radiation calculated using three types of equations derived from [Bethe and Hietler] equations .
The results have been compared with the data of Estar which shows a good agreement among the values that using the MATLAB Program .

Introduction:

The fast charged particles ionize the atoms or molecules when they passing through matter, which gradually lose energy in many small steps of interactions with targets. Stopping power is measured for example in MeV/cm. There are method to calculate SPs known as Bethe theory[1]. Stopping power is a necessary ingredient for many parts of basic science, for medical and for technological applications.[2]

The stopping power depends on the type and energy of the particle and on the properties of the material it passes. The main definition of the stopping power of the particles is 'energy loss per unit path length' which describes what happens to the particle in matter. The main equation which describes the losing of energy in matter is given by S.P = (-dE/dx) .....(1)

Where S.P (stopping powers), E: energy, and x is the path length. The minus sign makes positive.

This equation known as the linear stopping power which may be expressed in units MeV/mm . There is another stopping power called mass stopping power which can recognize a material from the another depending on density of each target , so one therefore often divides S(E) by the density of the material to obtain the mass stopping power which may be expressed in units like MeV/(mg/cm^2) or similar. The mass stopping power then depends only very little on the density of the material. Stopping power calculations for electrons and positrons are studied in two different ways: first is to consider the interactions of incoming electrons or positrons with the target electrons, which is called collision stopping power. The second is to consider the fact that accelerated charged particles is radiated, which is called radiative stopping power or Bremsstrahlung. Total stopping power is given as follows ICRU,37 [2] and study whoever (Gupta and Gupta, 1979)[3] :

$$\left(\frac{dT}{\rho dx}\right)_{total} = \left(\frac{dT}{\rho dx}\right)_{coll} + \left(\frac{dT}{\rho dx}\right)_{rad} \quad ...(2)$$

For molecular targets, we have used Bragg's rule [4] and applied it for the collisional stopping power and radiative stopping power separately and then found the total stopping power of the target. In this work we have studied and calculated SPs of beta in semiconductor because of the increasing of interesting of this subject especially in the last two decays.

Calculation of stopping powers for beta particles

1- Collision stopping power calculations:

The theory of the mass collision stopping power for heavy charged particles, electrons and positrons as a result of soft and hard collisions combines the Bethe theory[1], for soft collisions with the stopping power as a result of energy transfers due to hard collisions. The result of this, for a light charged particle with mass M and velocity v, ,as discussed by Evans (1955)[5], and Kase and Nelson (1978)[4]. The resulting formula, common to both particles. where the energy transfer due to hard collisions is limited to

Where $\tau = \frac{T}{m_0c^2}$ .... (3)

$$\left(\frac{dT}{\rho dx}\right)_c = k\left[\ln\left(\frac{\tau^2(\tau+2)}{2(I/m_oc^2)^2}\right) + F^-(\tau) - \delta - \frac{2C}{Z}\right] \ldots (4)$$

Where

C= $\pi\left(\frac{N_AZ}{A}\right)r_\circ^2$, $k = \frac{2C m_\circ c^2 z^2}{\beta^2}$ = 0.1535 $\frac{Zz^2}{A\beta^2}\frac{MeV}{g/cm^2}$

$r_\circ$: is the classical electron radius ($r_\circ = \frac{e^2}{m_\circ c^2}$ =2.82×10^{-15} m).

z :is the projectile charge in units of electron charge;

I: is the mean excitation potential of the medium;

C/Z :is the shell correction.

$F^-(\tau)$: faction stopping power for electrons .

Electron rest mass energy - $m_\circ c^2$ = 0.511MeV

τ Kinetic energy meaning rest mass, $\beta = v/c$ is related to the kinetic energy T by for [10]:

$$T = M_0c^2\left[\frac{1}{\sqrt{1-\beta}} - 1\right] \quad and\ \beta = \left[1 - \left(\frac{1}{\frac{T}{M_0c^2}}\right)^2\right]^{1/2} \quad ...(5)$$

The mean excitation potential I is a geometric mean value of all ionization and excitation potentials of an atom of the absorbing material. Since binding effects influence the exact value of I, calculation models are often inadequate to estimate its value accurately. Hence, I values are usually derived from measurements of stopping powers in heavy charged particle beams, for which the effects of scattering in these measurements is minimal. For elemental materials (I) varies approximately linearly with Z, with, on average, The following approximate empirical formulas can be used to estimate the I value in eV for an element with atomic number Z , Dalton [7] .

$$I \cong \left\{\begin{array}{ll} 19.0\ \text{eV}, & Z = 1\ (\text{hydrogen}) \\ 11.2 + 11.7\,Z\ \text{eV}, & 2 \le Z \le 13. \\ 52.8 + 8.71\,Z\ \text{eV}, & Z > 13. \end{array}\right\} ..(6)$$

For electrons and positrons, energy transfers due to soft collisions are combined with those due to hard collisions using the Møller (for electrons) and Bhabba (for positrons) cross-sections for free electrons. The complete mass collisional stopping power for electrons and positrons, according to ICRU, Report No. 37 [2], is:

$$\left(\frac{dT}{\rho dx}\right)_{coll} = \text{k}\left[\ln\left(\frac{\tau^2(\tau+2)}{2(I/m_oc^2)^2}\right) + F^-(\tau)\right] ....(7)$$

with F^- give for electron as:

$$F^-(\tau) = 1 - \beta^2 + \left(\frac{\frac{\tau^2}{8} - (2\tau+1)\ln 2}{(\tau+1)^2}\right) \quad ....(8)$$

Since the number of collisions an ion experiences with electrons is large, and since the charge state of the ion while traversing the medium may change frequently, it is very difficult to describe all possible interactions for all possible ion charge states. Instead, the electronic stopping power is often given as a simple function of energy $S.P$ which is an average taken over all energy loss processes for different charge states. An experimental values of the electronic stopping powers in many substances have been given by Paul [8] Only at extremely high ion energies,[2].

2. Radiation stopping power (Bremsstrahlung):

It is well-known that charged particles radiate when they accelerated or deaccelerated. Because of the mass of electron being much lower than the nucleus, when incident electrons come into the electromagnetic field of nucleus, they have gain a high acceleration and radiate, which is called Bremsstrahlung. Since an electron loses its energy quickly when moving inside a stopping medium, the dealing with bremsstrahlung for electrons is important especially at high energies

The mass radiative stopping power is the rate of energy loss by electrons or positrons that results in the production of bremsstrahlung . The (Bethe–Heitler) [11] and Berger and Seltzer (1983) [12], theory leads to the following formula for the mass radiative stopping Power (ICRU 37) [2] :

$$\left(\frac{dT}{\rho dx}\right)_{rad} = \sigma_\circ \frac{N_A Z^2}{A}(\text{E} + m_0c^2)\ \text{B} \ ...(9)$$

where the constant $\sigma_\circ = \frac{1}{137}(e^2/m_0c^2) = 5.80\times10^{-28}$ cm^2 /atom, T is the particle kinetic energy in MeV, and B, is a slowly varying function of Z and T having a value of $\frac{16}{3}$ for T << 0.5 MeV, and roughly 6 for T = 1 MeV, 12 for 10 MeV, and 15 for 100 MeV.

Stopping Power in Compounds and Mixtures calculation:

The mass collision stopping power, the mass radiative stopping power, and their sum the mass stopping power *can* all be well approximated for intimate mixtures of elements, or for chemical compounds, through the assumption of Bragg's Rule (ICRU,1984a) [2]. It states that atoms contribute nearly independently to the stopping power, and hence their effects are additive. This neglects the influence of chemical binding on I, In terms of the weight fractions fz_1, fz_2, of elements of atomic numbers Z_1 , Z_2 etc. present in a compound or mixture, the mass stopping power $(dT/\rho dx)_{mix}$ can be written as [6]:

$$\left(\frac{dT}{\rho dx}\right)_{mix} = fz_1\left(\frac{dT}{\rho dx}\right)_{z_1} + fz_2\left(\frac{dT}{\rho dx}\right)_{z_2} + \cdots \ ...(10)$$

where all stopping powers refer to a common kinetic energy and type of charged particle.

Results and discussion

In this calculated the total stopping power of electrons on semiconductor for composite ZnO which weight by fraction for oxygen(21.052) and Zinc (78.948) that two element sum we get percent by using bragg rule, also by summation the collision stopping power and radiation stopping power (bremsstrahlung) and we have compared our results with the data of Estar programmed which based on ICRU no. 37 [9] results are as below:

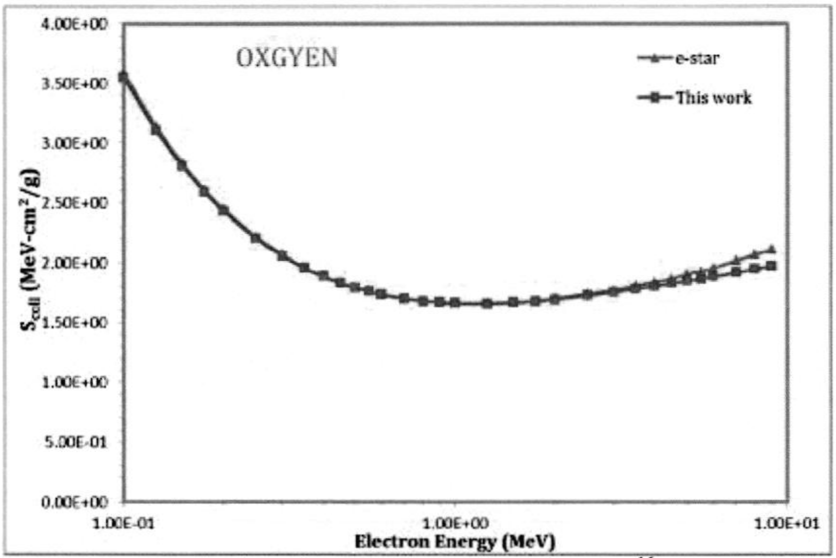

Fig.(1): shows collision stopping power for ^{16}O .

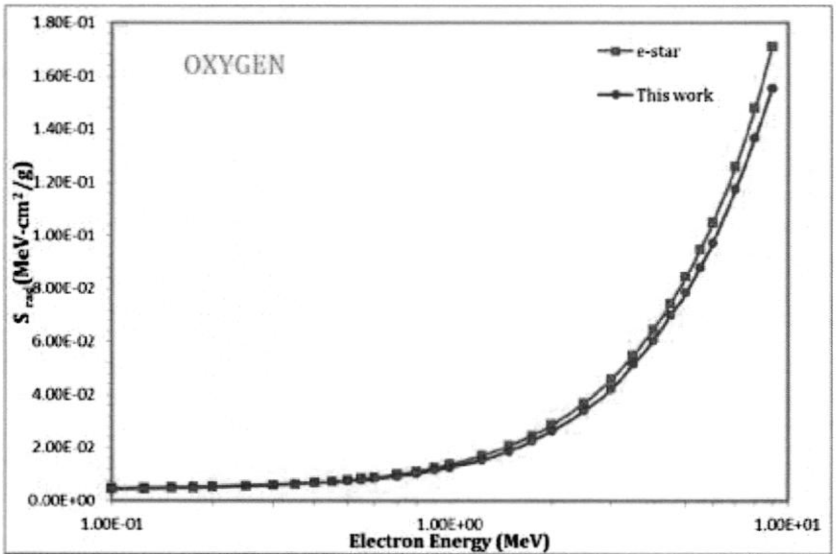

Fig. (2) shows radiation stopping power (bremsstrahlung) for ^{16}O .

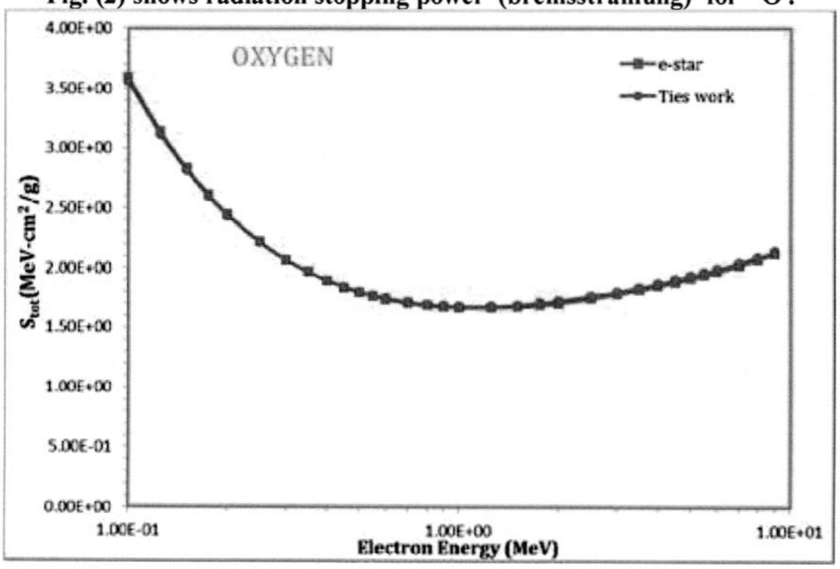

Fig.(3): shows total stopping power for ^{16}O .

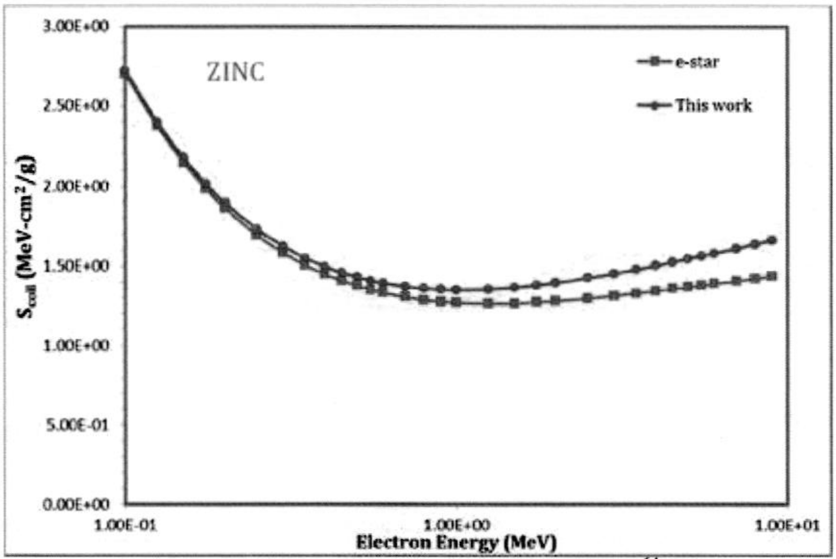

Fig.(4): shows collision stopping power for ^{64}Zn

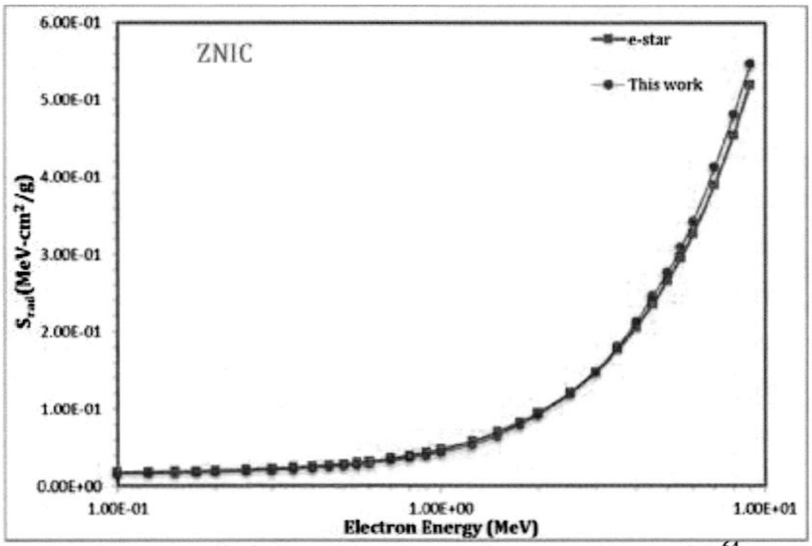

Fig.(5)shows radiation stopping power (bremsstrahlung) for ^{64}Zn.

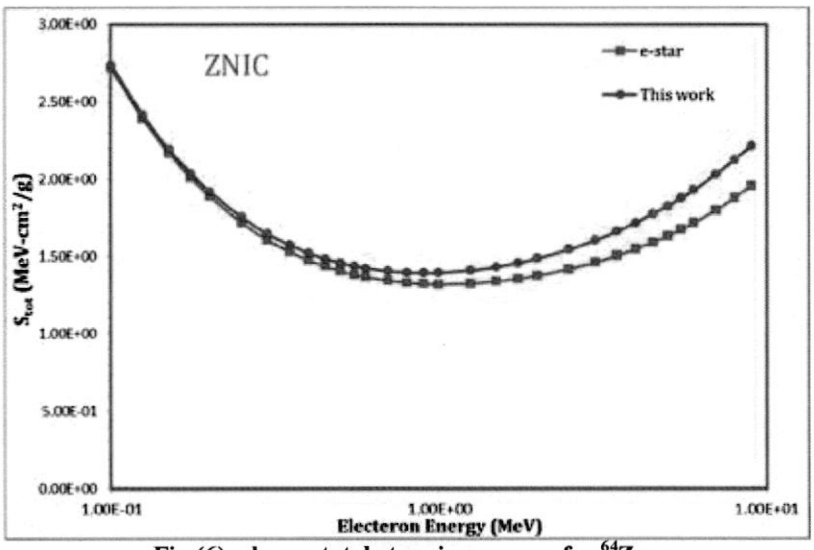

Fig.(6): shows total stopping power for ^{64}Zn..

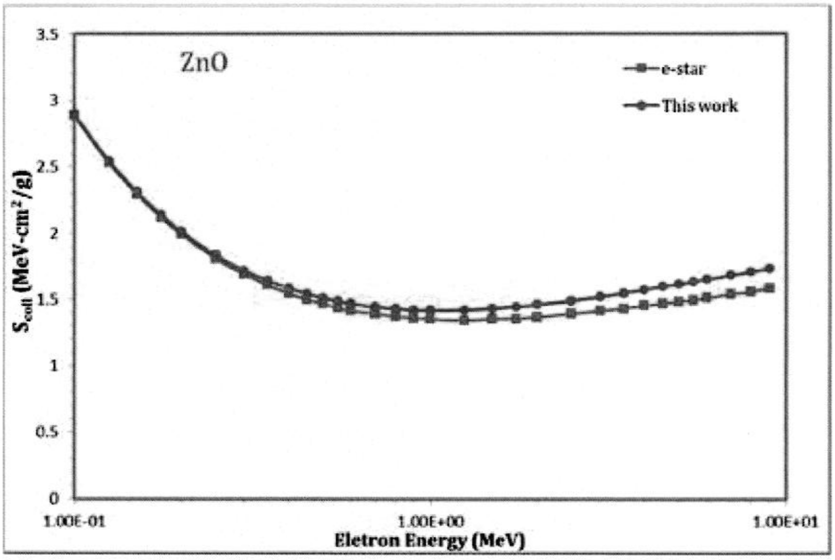

Fig.(7): shows collision stopping power for ZnO .

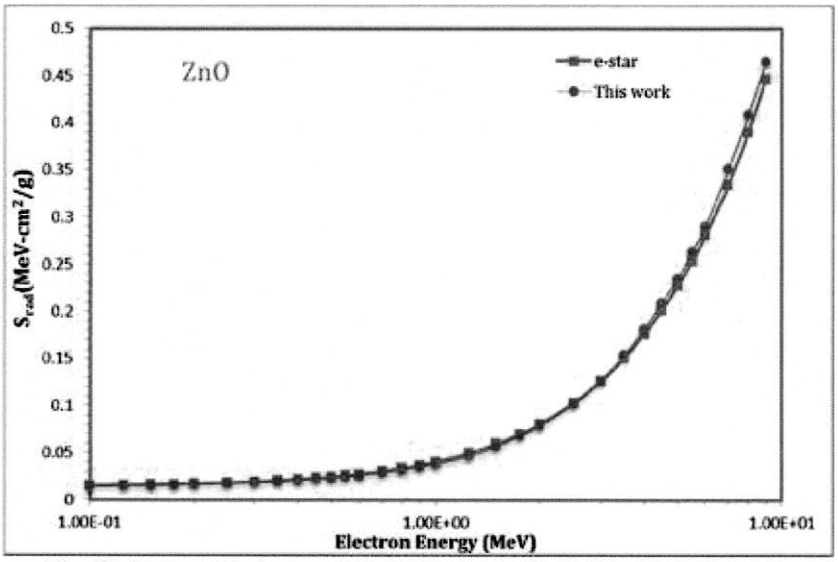

Fig.(8)shows radiation stopping power (bremsstrahlung) for ZnO.

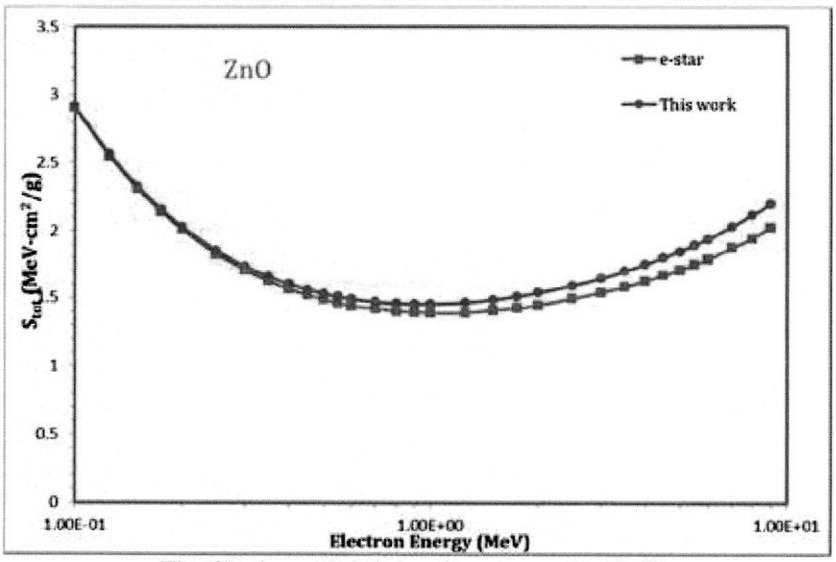

Fig.(9): shows total stopping power for ZnO .

In these figures one can notes that at collision stopping power is very high at low energy because is Dominic collision stopping power on interaction, but they decrease at high energy and the radiation stopping power is very high as we can see in figure (7). On the another the radiation stopping power is a low energies the very little but they increased at high energies (as we can see in figure 8), because they loss most of its energy by collision stopping power . A compression between radiation stopping power and the results of the program (Estar) shows a good agreement so as collision stopping power, and total stopping power (figure 9) and can be error ratio lass 6% . To improve our results we must apply some correction of shell correction or the effective atomic number.

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حساب قدرة الايقاف الكلية الكتلية (التصادمية والاشعاعية) للإلكترونات في شبه الموصل المركب ZnO لمدى الطاقات الواطئة والمتوسطة

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الملخص

تتفاعل الجسيمات المشحونة مع المواد بطرق عديدة ، الطريقة الاولى قدرة الايقاف . وتم في هذا البحث حساب قدرة الايقاف الكلية (الكتلية) باستخدام معادلات [Bethe – Block] في مركب شبه الموصل ZnO ضمن مدى الطاقات MeV (0.1 – 9) .

تتكون قدرة الايقاف الكلية (الكتلية) من نوعين من التفاعلات ، الاول يدعى قدرة الايقاف التصادمية $(-dE/dx)_{col}$، و الثاني قدرة الايقاف الاشعاعية $(-dE/dx)_{rad}$. أن قدرة الايقاف التصادمية تم حسابها باستخدام معادلة Bethe ، وقدرة الايقاف الاشعاعية تم حسابها باستخدام ثلاثة انوع من المعادلات تم اشتقاقها من قبل [Bethe and Hietler] .

والنتائج تم مقارنتها مع البيانات الخاصة ببرنامج Estar والتي اوضحت تطابقا جيدا بين القيم وذلك باستخدام برامج الماتلاب .