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# Study of the influence of numerical techniques of radiation in laser-matter interaction problems

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**Abstract**

It is well known that the influence of radiation has to be taken into account in numerical simulations in order to obtain realistics results. The aim of this work has been to develop comparison between different techniques for radiation transport. In this work, we use two methods: $S_n$ multigroup radiation transport in AMR [1] and $M_1$ moment technique [2]. To compare these codes we have reproduced several benchmarks existing in literature, showing the different performance of each method. To finish with, we have done a test that simulates the interaction between cone and shell in a fast ignition device. The results obtained are assessed and related to the characteristics of each technique.

## 1. Introduction

One of the main difficulties presented in simulation of radiation problems is the angular dependence of transport equation. Different numerical techniques can be employed to overcome this. The simplest one is diffusion approximation, which does not take into account this dependence. However, there are many cases where this simplification cannot be assumed and other method must be used. We will present in this work two of them, $M_1$ model [3] and $S_n$ discrete ordinates method characterised by its distinct treatment of the angular dependence and consequently its different computational costs and accuracy.

## 2. Methods for radiation

### 2.1. $S_n$ method

In $S_n$ method, the radiation equation is solved in a discrete number of directions, determined by the number $n$ of $S_n$ scheme. This method solves directly the radiation transport equation, but it has an important computational cost and can pressent ray-effect problems. It is well known that an acceleration technique must be employed so that a good convergence rate can be achieved. For this paper, we have used the code ARWEN uses diffusion synthethic acceleration scheme (DSA). Another important characteristic of this code is the implementation of an Adaptive Mesh Refinement scheme (AMR) [4], suitable for cases with strong gradients. In this paper, all simulations will be done in $S_8$.

### 2.2. $M_1$ method

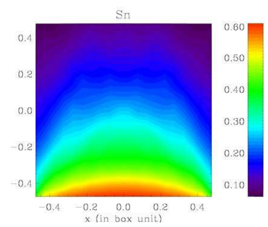
In $M_1$ the transfer equation is approximated by its moments equations. The unique equation over the specific intensity is then replaced by two equations over the radiative energy and flux, moments of order zero and one respectively. To solve the problem, a closure relation is then needed which relies the different moments among each other. The advantage of the M1 closure [3] is that it is analytical and correct both in the diffusive and the transport limit (regions optically thick and thin, respectively). The main drawback is that it solves the moments equations which are an approximation of the transfer equation. The code we are going to use in this paper is HERACLES [2].

## 3. Benchmark tests

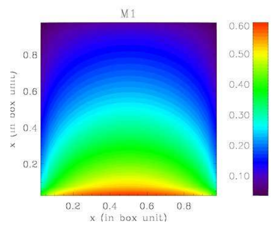
### 3.1. Mishra test

The aim of this test is to show the differences between $M_1$ and $S_n$ in the case of a radiation front expanding across a domain. The test, presented in [5], consist in a cold medium in equilibrium with a hot wall. The data presented are $(T_e/T_s)^4$ where $T_e$ is the electronic temperature and $T_s$ the hot wall temperature. The rest of walls are at zero temperature. The dimensions are a unit square with a 20x20 mesh and the opacity is 1. The results are presented in fig. 1.

It can be clearly observed the difference between $M_1$, that gives a smooth wave front, and $S_8$, which presents ray effect, which is due to the fact that discrete ordinates scheme has privileged directions. The ray effect increases with the distance to the radiation source, as can be observed in fig. 1(a).




(a) $S_n$ model



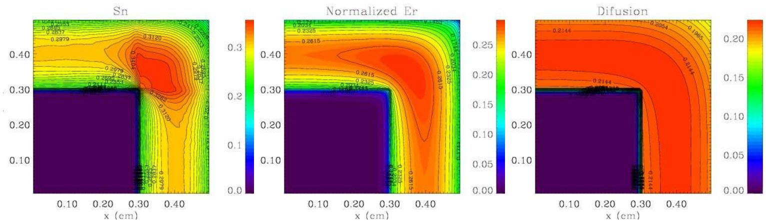

(b) $M_1$ model

Figure 1: Solutions for $\beta$=1 in the Mishra test

### 3.2. The Mordant test

To check the capability of the two methods in a 2D slab geometry, we have used the test presented in [6]. This tests consists in a long rod with dimensions of a unit square with a 60x60 mesh, a total cross section equal to 1, a scattering cross section of 0.95 and a unit planck function emissivity. Its center has been replaced by a 0.6 square rod with a total cross section of 100, no scattering and no emission.

As can be observed in the figures, the most accurate result is obtained with $S_n$ method, that shows a corner effect that cannot be reproduced by the other methods. The $M_1$ model presents a reasonable convergence to the transport equation. The main differences are that $M_1$ maximum is lower than transport one and that radiation penetrates deeper in center rod. Finally, the diffusion method present an important disagreement in comparison to the other methods. It reaches a lower maximum and does not present any special heating effect near the corner.




(a) $S_n$ model (b) $M_1$ model (c) Diffusion model

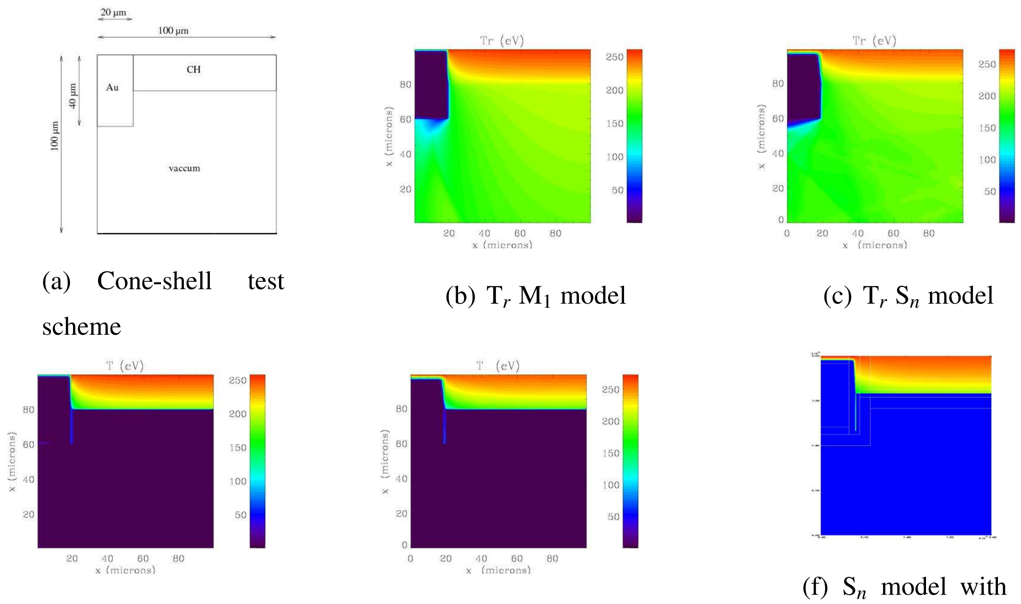
Figure 2: 2D maps in the Mordant test

## 4. The cone-shell test

In this section we present the results of $S_8$ and $M_1$ method for an academic test [7]. Our aim is to simulate the interaction between a capsule and a gold cone in a fast ignition problem. The test consists in a two dimensional slab domain as sketched in 3(a). In this geometry, a radiation flux of 290 eV comes from the upper boundary, while left and right side have a wall boundary condition and bottom side a free boundary condition. We use an ideal gas equation of state with $\gamma$ of 5/3 and the opacity of materials as follows a law $\kappa(cm^2/g) = e^a \rho(g/cm^3)^b T(eV)^c$ [8].

The values used for Au: $\rho$=19.32$g/cm^3$, a=17.17, b=0.33, c=-2.01, Z=30, A=196.96, for CH: $\rho$=0.954 $g/cm^3$, a=15.93, b=0.78, c=-1.87, Z=3, A=6.5 and for vacuum, density is $10^{-7}$ $g/cm^3$, Z=3, A=6.5 and opacity equal to zero. The initial temperature is 300 K and no scatering is considered. The results obtained by different methods at 80 ps. are shown in fig. 2

The simulations shown have been calculated on a 100x100 mesh, employing a $S_8$ for the discrete ordinates simulations. The radiation wave propagate across the CH layer until it reaches the vacuum zone. In that moment radiation propagates across all the domain suddenly, heating the right side of gold block. This heating could affect the implosion process of fast ignition, due to the subsequenlty expansion of gold plasma. The bottom part of gold block present a shadow effect that can be observed in 3(b) and 3(c). The $S_8$ method reproduces clearly this situation while $M_1$ present divergences due to an approximative treatment of bottom boundary condition that induces some reflection of radiation that heats the rear side of gold as is shown in 3(d). Another difference that can be observed is that heating of gold block external surface is uniform in $M_1$ method, whereas $S_n$ present a stronger heating in the region far away from CH layer. This effect is due to the tendence of discrete ordinates scheme to employ privileged directions in comparison to the more uniform treatment provided by $M_1$. To finish with, we present here a comparison of electronic temperature with adaptive mesh refinemt (AMR) in fig. 3(f). By using this method, the mesh is finer where strong gradients of density and internal energy take place. It can be observed that the effect of non uniformity of heating in gold surface is smoothed and the width of hot zone is more accurately delimited.




(a) Cone-shell test scheme

(b) $T_r$ $M_1$ model

(c) $T_r$ $S_n$ model

(d) $T_e$ $M_1$ model

(e) $T_e$ $S_n$ model

(f) $S_n$ model with AMR

Figure 3: Result in cone-shell test

## 5. Conclusions

We have presented a comparison between two methods for modelling radiation: $M_1$ and $S_n$. For a case of a boundary source, $M_1$ and $S_n$ give similar results, although $S_n$ solution presents problems of ray effect in zones away from the source. For cases where angular resolution has an important role, as in Mordant test, $M_1$ tends to present a too smoothed behaviour, but it offers a better precision than the diffusion case. To finish with, we have presented a case that simulates what could happen in a fast ignition device. Both method show clearly the superficial heating in gold cone, but $S_n$ method tends to present a non uniformity in heating of gold due to ray effect. This heating can be of importance in fast ignition, because a preheating of gold could lead to an expansion of plasma that would affect the implossion process.

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