On a nonlinear elliptic problems having large monotonicity with L^1 -data in weighted Orlicz-Sobolev spaces

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ABSTRACT. We prove in weighted Orlicz-Sobolev spaces, the existence of entropy solution for a class of nonlinear elliptic equations of Leray-Lions type, with large monotonicity condition and right hand side $f \in L^1(\Omega)$.

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1. Introduction

This paper deals with existence of solutions to the following nonlinear Dirichlet problem

$$\begin{cases} A(u) = f(x) & \text{in } \Omega, \\ u = 0 & \text{on } \partial\Omega, \end{cases} \quad (1.1)$$

where $A(u) = -\operatorname{div}(\rho(x)a(x, u, \nabla u))$, Ω is a bounded domain of $\mathbb{R}^N$, $N \geq 2$. $a(x, u, \nabla u) = (a_i(x, u, \nabla u))_{1 \leq i \leq N}$, $a_i : \Omega \times \mathbb{R} \times \mathbb{R}^N \rightarrow \mathbb{R}$ is a Carathéodory functions (that is measurable with respect to x in Ω for every $(s, \xi) \in \mathbb{R} \times \mathbb{R}^N$, and continuous with respect to $(s, \xi) \in \mathbb{R} \times \mathbb{R}^N$ for almost every $x \in \Omega$) such that for all ξ, ξ' in $\mathbb{R}^N$,

$$|a_i(x, s, \xi)| \leq |\phi_i(x)| + K_i \bar{P}^{-1}(\rho^{-1}(x)M(c_2|s|)) + K_i \bar{M}^{-1}M(c_1|\xi|), \quad (1.2)$$

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$$(a(x, s, \xi) - a(x, s, \xi'))(\xi - \xi') \geq 0, \quad (1.3)$$

$$a(x, s, \xi)\xi \geq M(\lambda_1|\xi|), \quad (1.4)$$

where c_1, c_2, λ_1 and K_i belongs to $\mathbb{R}_+$. M, P be two N-functions such that $P \prec\prec M$. Moreover $\overline{M}, \overline{P}$ be the complementary functions of M and P respectively, ρ be a weight function on Ω (that is, measurable and positive a.e. on Ω) and $\phi_i \in E_{\overline{M}}(\Omega, \rho)$.

$$f \in L^1(\Omega), \quad (1.5)$$

It is well known that in the setting of weighted Orlicz–Sobolev spaces include many spaces as special spaces, such as Lebesgue spaces, weighted Lebesgue spaces and Orlicz spaces; see [19]. These spaces have many applications in various fields such as PDE, electrorheological fluids, and image restoration; see [11, 10, 15].

The feature of this paper, is to treat a class of problems for which the classical monotone operator methods (developed by Minty [18], Browder [9], Brézis [8] and Lions [16] in $W_0^{1,p}(\Omega)$ case) do not apply. The reason for this, is that $a(x, u, \nabla u)$ does not need to satisfy the strict monotonicity condition that is,

$$(a(x, s, \xi) - a(x, s, \xi'))(\xi - \xi') > 0, \text{ for all } \xi, \xi' \in \mathbb{R}^N, (\xi \neq \xi'),$$

of a typical Leray–Lions operator but only a large monotonicity that is

$$(a(x, s, \xi) - a(x, s, \xi'))(\xi - \xi') \geq 0, \text{ for all } \xi, \xi' \in \mathbb{R}^N,$$

The aim of this paper is to demonstrate the existence of solutions for (1.1) under the weaker assumption large monotonicity condition, without using the almost everywhere convergence of the gradients of the approximate equations, since this is impossible to prove in our setting. The main tools of our proof are a version of Minty's Lemma (Now we use an idea of G. J. Minty [17]).

The paper is organized as follows: We introduce some basic definitions and properties in the setting of weighted Orlicz–Sobolev spaces as well as an abstract theorem and we prepare some auxiliary results to prove our theorem, in the next section 2. In the final section 3, we state the main result and proofs.

2. Preliminary

This section present, some definitions and well-known about N-functions, weighted Orlicz–Sobolev spaces (standard references see [1] and [12]).

2.1. N-function. Let $M : \mathbb{R}^+ \rightarrow \mathbb{R}^+$ be an N-function, i.e. M is continuous, convex, with

$$M(t) > 0 \text{ for } t > 0, \quad \frac{M(t)}{t} \rightarrow 0 \text{ as } t \rightarrow 0 \text{ and } \frac{M(t)}{t} \rightarrow \infty \text{ as } t \rightarrow \infty.$$

Equivalently M admits the representation :

$$M(t) = \int_0^t m(\tau) d\tau,$$

where $m : \mathbb{R}^+ \rightarrow \mathbb{R}^+$ is non-decreasing right continuous, with $m(0) = 0$, $m(t) > 0$ for $t > 0$ and $m(t) \rightarrow \infty$ as $t \rightarrow \infty$. The N-function $\overline{M}$ conjugate to M defined by

$$\overline{M}(t) = \int_0^t \overline{m}(\tau) d\tau,$$

where $\overline{m} : \mathbb{R}^+ \rightarrow \mathbb{R}^+$ is given by $\overline{m}(t) = \sup \{s : m(s) \leq t\}$. It is well known that we can assume that m and $\overline{m}$ are continuous and strictly increasing. We will extend the N-functions into even function on all $\mathbb{R}^+$.

Clearly $\overline{\overline{M}} = M$ and has Young's inequality

$$st \leq M(t) + \overline{M}(s) \text{ for all } s, t \geq 0.$$

The N-function M is said to satisfy the Δ_2 -condition every-where (resp. infinity) if there exist $k > 0$ (resp. $t_0 > 0$) such

Let P and Q be two N-functions, the notation $P \prec\prec Q$ means that P grows essentially less rapidly than Q , that is to say for all $\epsilon > 0$, $\frac{P(t)}{Q(\epsilon t)} \rightarrow 0$ as $t \rightarrow +\infty$. That is the case if and only if $\frac{Q^{-1}(t)}{P^{-1}(t)} \rightarrow 0$ as $t \rightarrow \infty$.

2.2. Orlicz-Sobolev space. Let Ω be an open subset of $\mathbb{R}^N$ and M be an N-function.

The Orlicz classe $K_M(\Omega)$ (resp. the Orlicz spaces $L_M(\Omega)$) is the set of all (equivalence classes modulo equality a.e. in Ω of) real-valued measurable functions u defined in Ω and satisfying

$$\int_{\Omega} M(u(x))dx < \infty \left(\text{resp. } \int_{\Omega} M\left(\frac{|u(x)|}{\lambda}\right)dx < \infty \text{ for some } \lambda > 0 \right).$$

$L_M(\Omega)$ is a Banach space under the norm :

$$\|u\|_{M,\Omega} = \inf \left\{ \lambda > 0 : \int_{\Omega} M\left(\frac{|u(x)|}{\lambda}\right)dx \leq 1 \right\}. \quad (2.1)$$

The closure in $L_M(\Omega)$ of the set of bounded measurable function with compact support in $\overline{\Omega}$ is denoted by $E_M(\Omega)$ (we have usual $E_M(\Omega) \subset K_M(\Omega) \subset L_M(\Omega)$).

The equality $L_M(\Omega) = E_M(\Omega)$ hold if and only if M satisfies the Δ_2 -condition, for all t or for t large according to whether Ω has a infinite measure or not.

The dual of $E_M(\Omega)$ can be identified with $L_{\overline{M}}(\Omega)$ by means of the pairing $\int_{\Omega} u(x)v(x)dx$ where $u \in L_M(\Omega)$ and $v \in L_{\overline{M}}(\Omega)$ and the dual norm on $L_{\overline{M}}(\Omega)$ is equivalent to $\|\cdot\|_{\overline{M},\Omega}$.

The space $L_M(\Omega)$ is reflexive if and only if M and $\overline{M}$ satisfy the Δ_2 -condition for all t or for t large, according to whether Ω be infinite measure or not.

We return now to the Orlicz-Sobolev spaces $W^1 L_M(\Omega)$ (resp. $W^1 E_M(\Omega)$) is the space of all function u such that u and its distributional derivatives up to order 1 lie in $L_M(\Omega)$ (resp. in $E_M(\Omega)$). It's Banach space under the norm :

$$\|u\|_{1,M} = \sum_{|\alpha| \leq 1} \|D^{\alpha} u\|_{M,\Omega}. \quad (2.2)$$

Thus $W^1 L_M(\Omega)$ and $W^1 E_M(\Omega)$ can be identified with subspaces of $\prod L_M$ we have the weak topology $\sigma(\prod L_M, \prod E_{\overline{M}})$ and $\sigma(\prod L_M, \prod L_{\overline{M}})$.

The space $W_0^1 E_M(\Omega)$ (resp. $W_0^1 L_M(\Omega)$) is defined by the closure of $D(\Omega)$ in $W^1 E_M(\Omega)$ (resp. $W^1 L_M(\Omega)$) for the norm (2.2) (resp. for the topology $\sigma(\prod L_M, \prod E_{\overline{M}})$).

Definition 2.1. The sequence u_n converges to u in $L_M(\Omega)$ for the modular convergence (denoted by $u_n \rightarrow u \pmod{L_M(\Omega)}$) if $\int_{\Omega} M\left(\frac{|u_n - u|}{\lambda}\right)dx \rightarrow 0$ as $n \rightarrow \infty$ for some $\lambda > 0$.

2.3. Weighted Orlicz-Sobolev space. Let Ω be a domain in $\mathbb{R}^N$, M be an N-function and $\rho(x)$ be a weight function on Ω , i.e. measurable positive a.e. on Ω such that :

$$\rho \in L^1(\Omega) \quad (2.3)$$

The weighted Orlicz classe $K_M(\Omega, \rho)$ (resp. the weighted Orlicz space $L_M(\Omega, \rho)$) is the set of all (equivalence classes modulo equality a.e. in Ω) of real-valued measurable functions u defined in Ω and satisfying

$$m_{\rho}(u, M) = \int_{\Omega} M(|u(x)|)\rho(x)dx < \infty$$

$$\left(\text{resp. } m_{\rho}\left(\frac{u}{\lambda}, M\right) = \int_{\Omega} M\left(\frac{|u(x)|}{\lambda}\right)\rho(x)dx < \infty \text{ for some } \lambda > 0 \right).$$

$L_M(\Omega, \rho)$ is a Banach space under the norm :

$$\|u\|_{M,\rho} = \inf \left\{ \lambda > 0; m_{\rho}\left(\frac{u}{\lambda}, M\right) \leq 1 \right\}. \quad (2.4)$$

The closure in $L_M(\Omega, \rho)$ of the set of bounded measurable function with compact support in $\bar{\Omega}$ is denoted by $E_M(\Omega, \rho)$ (we have usual $E_M(\Omega, \rho) \subset K_M(\Omega, \rho) \subset L_M(\Omega, \rho)$).

The equality $L_M(\Omega, \rho) = E_M(\Omega, \rho)$ hold if and only if M satisfies the Δ_2 -condition, for all t or for t large according to whether Ω has a infinite mesure or note.

Remember that spaces $L_M(\Omega, \rho)$ and $L_{\bar{M}}(\Omega, \rho)$ are naturally associated by duality

$$\langle u, v \rangle = \int_{\Omega} u(x)v(x)\rho(x)dx, u \in L_M(\Omega, \rho), v \in L_{\bar{M}}(\Omega, \rho)$$

giving what's called the orlicz norm on $L_M(\Omega, \rho)$, which is

$$\|u\|_{M,\rho} = \sup \left\{ \int_{\Omega} u(x)v(x)\rho(x)dx, m_{\rho}(v, \bar{M}) \leq 1 \right\}$$

can be identify the dual of $E_M(\Omega, \rho)$ with $L_{\bar{M}}(\Omega, \rho)$ (see [21])

It is easy to prove (as in the case of non-weighted spaces) that

$$\|u\|_{M,\rho} \leq \|u\|_{M,\rho} \leq 2\|u\|_{M,\rho}$$

The space $L_M(\Omega, \rho)$ is reflexive if and only if M an $\bar{M}$ satisfy the Δ_2 -condition for all t or for t large according to whether Ω be infinite measure or note.

We return now to the weighted Orlicz-Sobolev spaces $W^1 L_M(\Omega, \rho)$ (resp. $W^1 E_M(\Omega, \rho)$) is the space of all function u such that $u \in L_M(\Omega)$ (resp. $u \in E_M(\Omega)$) and its distributional derivatives up to order 1 lie in $L_M(\Omega, \rho)$ (resp. $E_M(\Omega, \rho)$). It's Banach space under the norm

$$\|u\|_{1,M,\rho} = \|u\|_M + \|\nabla u\|_{M,\rho}, \quad (2.5)$$

(where $\|u\|_M = \|u\|_{M,\Omega}$). Thus $W^1 L_M(\Omega, \rho)$ and $W^1 E_M(\Omega, \rho)$ can be identified with subspaces of $\prod L_{M,\rho} = L_M \times \prod L_M(\Omega, \rho)$ we have the weak topology $\sigma(\prod L_{M,\rho}, \prod E_{\bar{M},\rho})$ and $\sigma(\prod L_{M,\rho}, \prod L_{\bar{M},\rho})$. The space $W_0^1 E_M(\Omega, \rho)$ (resp. $W_0^1 L_M(\Omega, \rho)$) is defined by the closure of $D(\Omega)$ in $W^1 E_M(\Omega, \rho)$ (resp. $W^1 L_M(\Omega, \rho)$) for the norm (2.5) (resp. for the topology $\sigma(\prod L_{M,\rho}, \prod E_{\bar{M},\rho})$).

Definition 2.2. The sequence u_n converges to u in $L_M(\Omega, \rho)$ for the modular convergence (denoted by $u_n \rightarrow u \text{ (mod)}$ $L_M(\Omega, \rho)$) if $\int_{\Omega} M\left(\frac{|u_n - u|}{\lambda}\right)\rho(x)dx \rightarrow 0$ as $n \rightarrow \infty$ for some $\lambda > 0$.

Definition 2.3. The sequence u_n converges to u in $W^1 L_M(\Omega, \rho)$ for the modular convergence (denoted by $u_n \rightarrow u \text{ (mod)}$ $W^1 L_M(\Omega, \rho)$) if for some $\lambda > 0$ $\int_{\Omega} M\left(\frac{|u_n - u|}{\lambda}\right)dx \rightarrow 0$ as $n \rightarrow \infty$ and $\int_{\Omega} M\left(\frac{|D^{\alpha}(u_n - u)|}{\lambda}\right)\rho(x)dx \rightarrow 0$ as $n \rightarrow \infty$ for $|\alpha| = 1$.

Lemma 2.1. [3] Let M be an N -function. If $u_n \in L_M(\Omega)$ converges a.e. to u and u_n bounded in $L_M(\Omega)$, then $u \in L_M(\Omega)$ and $u_n \rightarrow u$ for the topology $\sigma(L_M(\Omega), E_{\bar{M}}(\Omega))$.

Lemma 2.2. [3] If the sequence $u_n \in L_M(\Omega, \rho)$ converges to u a.e. and bounded in $L_M(\Omega, \rho)$, then $u \in L_M(\Omega, \rho)$ and $u_n \rightarrow u$ for the topology $\sigma(L_M(\Omega, \rho), E_{\bar{M}}(\Omega, \rho))$.

2.4. Compactness results. Let Ω an open bounded locally-border lipschitzian in $\mathbb{R}^N$, ρ the weight function and M an N -function. Let the following integrability assumptions :

There exists a real $s > 0$ such that :

$$(M(t))^{\frac{s}{s+1}} \text{ be } N\text{-function and that } \rho^{-s} \in L^1(\Omega), \quad (2.6)$$

$$\int_1^{\infty} \frac{t}{M(t)^{1+\frac{s}{N(s+1)}}} dM(t) = \infty, \quad (2.7)$$

$$\lim_{t \rightarrow \infty} \frac{1}{M^{-1}(t)} \int_0^{t^{\frac{s+1}{s}}} \frac{M^{-1}(u)}{u^{1+\frac{s}{N(s+1)}}} du = 0. \quad (2.8)$$

Remark 2.1. In the particular case where $M(t) = \frac{|t|^p}{p}$ ($1 < p < \infty$), the first part of (2.6) is satisfied if $s > \frac{1}{p-1}$.

Theorem 2.1 (See[2] Theorem 9-5). Let Ω an open bounded subset of $\mathbb{R}^N$ with locally-lipschitzian and M an N -function. Suppose that assumptions (2.6)–(2.8) are satisfied. So we have the following compact injection :

$$W^1 L_M(\Omega, \rho) \hookrightarrow E_M(\Omega).$$

We will also use the following technical lemmas.

2.5. Some technical lemmas.

Lemma 2.3. Let $f_n, f \in L^1(\Omega)$ such that $f_n \geq 0$ a.e. in Ω , $f_n \rightarrow f$ a.e. in Ω et $\int_{\Omega} f_n(x) dx \rightarrow \int_{\Omega} f(x) dx$. Then $f_n \rightarrow f$ strongly in $L^1(\Omega)$.

Lemma 2.4. Let $F : \mathbb{R} \rightarrow \mathbb{R}$ be uniformly Lipschitzian, with $F(0) = 0$. Let $u \in W_0^1 L_M(\Omega, \rho)$. Then $F(u) \in W_0^1 L_M(\Omega, \rho)$. Moreover, if the set D of discontinuity points of F' is finite, then

$$\frac{\partial}{\partial x_i} F(u) = \begin{cases} F'(u) \frac{\partial u}{\partial x_i} & \text{a.e. in } \{x \in \Omega; u(x) \notin D\}, \\ 0 & \text{a.e. in } \{x \in \Omega; u(x) \in D\}. \end{cases}$$

Proof. We suppose for the moment that F is also C^1 , there exist a sequence $u_n \in D(\Omega)$ such that $u_n \rightarrow u \pmod{W^1 L_M(\Omega, \rho)}$. Passing to subsequence, we can assume that

$$D^\alpha u_n \rightarrow D^\alpha u \quad \forall |\alpha| \leq 1 \text{ a.e. in } \Omega.$$

From the relation $|F(s)| \leq k|s|$, where k denote the Lipschitz constant for F , and $\frac{\partial}{\partial x_i} F(u_n) = F'(u_n) \frac{\partial u_n}{\partial x_i}$, we deduce that $F(u_n)$ remains bounded in $W_0^1 L_M(\Omega, \rho)$. Thus going to to a further subsequence, we obtain

$$F(u_n) \rightarrow w \in W_0^1 L_M(\Omega, \rho) \text{ for } \sigma(\Pi L_{M,\rho}, \Pi E_{\overline{M},\rho}),$$

and also by a local application of the compact imbedding theorem, $F(u_n) \rightarrow w$ a.e. in Ω . Consequently $w = F(u)$, and $F(u) \in W_0^1 L_M(\Omega, \rho)$. Finally, by the usual chain rule for weak derivatives,

$$\frac{\partial}{\partial x_i} F(u) = F'(u) \frac{\partial u}{\partial x_i} \text{ a.e. in } \Omega. \quad (2.9)$$

For the general case. Taking convolution with the mollifiers, we get a sequence $F_n \in C^\infty(\mathbb{R})$ such that $F_n \rightarrow F$ uniformly on each compact, $F_n(0) = 0$ and $|F'_n| \leq k$. For each n , $F_n(u) \in W_0^1 L_M(\Omega, \rho)$, and we have (2.9) with F replaced by F_n . Finally (2.9) follows from the generalized chain rule for weak derivatives.

The following lemmas follow from the previous lemma.

Lemma 2.5. Let $u, v \in W_0^1 L_M(\Omega, \rho)$ and let $w = \min(u, v)$. Then $w \in W_0^1 L_M(\Omega, \rho)$ and

$$\frac{\partial w}{\partial x_i} = \begin{cases} \frac{\partial u}{\partial x_i} & \text{a.e. in } \{x \in \Omega; u(x) \leq v(x)\}, \\ \frac{\partial v}{\partial x_i} & \text{a.e. in } \{x \in \Omega; u(x) > v(x)\}. \end{cases}$$

Proof. Note that $\min(u, v) = u - (u - v)^+$ and apply Lemma 2.4 with $F(s) = s^+$.

We introduce the truncate operator. For a given constant $k > 0$, we define the function $T_k : \mathbb{R} \rightarrow \mathbb{R}$ as

$$T_k(s) = \begin{cases} s & \text{if } |s| \leq k, \\ k \frac{s}{|s|} & \text{if } |s| > k. \end{cases}$$

Lemma 2.6. Assume that (2.6)–(2.8) holds. Let $u \in W_0^1 L_M(\Omega, \rho)$, and let $T_k(u), k \in \mathbb{R}^+$, be the usual truncation then $T_k(u) \in W_0^1 L_M(\Omega, \rho)$. Moreover we have

$$T_k(u) \rightarrow u \text{ strongly in } W_0^1 L_M(\Omega, \rho).$$

Lemma 2.7. *Let u_n be a sequence in $W_0^1 L_M(\Omega, \rho)$ such that $u_n \rightharpoonup u$ for the topology $\sigma(\Pi L_{M,\rho}, \Pi E_{\overline{M},\rho})$. Then $T_k(u_n) \rightharpoonup T_k(u)$ for $\sigma(\Pi L_{M,\rho}, \Pi E_{\overline{M},\rho})$.*

Proof. Since $u_n \rightharpoonup u$ and $W_0^1 L_M(\Omega, \rho) \hookrightarrow E_M(\Omega)$, we have $u_n \rightarrow u$ strongly in $E_M(\Omega)$ and a.e. in Ω , then $T_k(u_n) \rightarrow T_k(u)$ a.e. in Ω . On the other hand, for some $\lambda > 0$,

$$\int_{\Omega} M\left(\frac{|T_k(u_n)|}{\lambda}\right) dx \leq \int_{\Omega} M\left(\frac{|u_n|}{\lambda}\right) dx$$

and

$$\int_{\Omega} M\left(\frac{|\nabla T_k(u_n)|}{\lambda}\right) \rho(x) dx = \int_{\Omega} M\left(\frac{|T_k'(u_n)| |\nabla u_n|}{\lambda}\right) \rho(x) dx \leq \int_{\Omega} M\left(\frac{|\nabla u_n|}{\lambda}\right) \rho(x) dx$$

imply that

$$\|T_k(u_n)\|_{1,M,\rho} \leq \|u_n\|_{1,M,\rho}.$$

Then $(T_k(u))_n$ is bounded in $W_0^1 L_M(\Omega, \rho)$ hence by Lemma 2.2, we have $T_k(u_n) \rightharpoonup T_k(u)$ in $W_0^1 L_M(\Omega, \rho)$ for $\sigma(L_M(\Omega, \rho), E_{\overline{M}}(\Omega, \rho))$.

Lemma 2.8. *If the sequence $u_n \in E_M(\Omega, \rho)$ converges a.e. in Ω with $\rho \in L^1(\Omega)$, then it converges in norm in $E_M(\Omega, \rho)$ if and only if the norms are uniformly absolutely continuous, i.e. for each $\epsilon > 0$ there exist $\delta > 0$ such that $\|u_n \chi_E\|_{M,\rho} < \epsilon$, for all n and $E \subset \Omega$ with $|E| < \delta$.*

Proof. by the same argument introduced in the proof of Lemma 11.2 in [13] we find $E_{n,m} = \{x \in \Omega : |u_n(x) - u_m(x)| > \alpha\}$ where $\alpha = M^{-1}\left(\frac{\epsilon}{3\|\rho\|_1}\right)$ and with $\delta > 0$ such that

$$\|u_n \chi_E\|_{M,\rho} < \frac{\epsilon}{3}.$$

We denote by $H(E_M(\Omega), r)$ the set of functions $u \in L_M(\Omega)$ whose distance to $E_M(\Omega)$ (with respect to the Orlicz norm) is strictly less than r and by $B_{L_M}(\Omega)(0, r)$ the ball in $L_M(\Omega)$ (with respect to the Orlicz norm) of radius r and center 0.

Lemma 2.9. *Let Ω be bounded subset of $\mathbb{R}^N$ with finite measure. let M, R and Q be N -functions such that $Q << R$, and let f be a Carathéodory function such that for a.e. $x \in \Omega$ and all $s \in \mathbb{R}$:*

$$|f(x, s)| \leq b(x) + k_1 R^{-1} \left(\rho^{-1}(x) Q(k_2 |s|) \right), \quad (2.10)$$

where $0 \leq b(x) \in E_M(\Omega, \rho), \rho \in L^1(\Omega)$ and $k_1, k_2 \in \mathbb{R}^+$. Then the Nemytskii operator

$$N_f(u)(x) = f(x, u(x))$$

satisfies :

- (1) Sends $\left(H(E_Q(\Omega), \frac{1}{k_2})\right)^p$ into $L_R(\Omega, \rho)$ and is continuous from $\left(H(E_Q(\Omega), \frac{1}{k_2})\right)^p$ to the norm topology of $(L_Q(\Omega))^p$ into $L_R(\Omega, \rho)$ to the modular convergence;
- (2) It's uniformly bounded on $\left(B_{L_Q}(\Omega)(0, \frac{1}{k_2})\right)^p$;
- (3) If $b(x) \in E_{R_1}(\Omega, \rho)$ with $R_1 << R$, then N_f is continuous to the norm topology of $E_{R_1}(\Omega, \rho)$.

Proof. (1) Let $u = (u_1, u_2, \dots, u_p) \in \left(H(E_Q(\Omega), \frac{1}{k_2})\right)^p$. Since $d(u_i, E_Q(\Omega)) < \frac{1}{k_2}$ ($1 \leq i \leq p$), we have $\int_{\Omega} Q(k_2 |u|) dx \leq 1$, (see Theorem 10.1 [13]). Let $\lambda \geq 2k_1$ such that $\frac{2b(x)}{\lambda} \in K_R(\Omega, \rho)$. By the growth condition (2.10) and the convexity of R , we get

$$\int_{\Omega} R\left(\frac{|f(x, s)|}{\lambda}\right) \rho(x) dx \leq \frac{1}{2} \int_{\Omega} R\left(\frac{2b(x)}{\lambda}\right) \rho(x) dx + \frac{1}{2} \int_{\Omega} R(k_2 |u(x)|) dx < \infty.$$

On the other hand, suppose that

$$u_n \rightarrow u \in \left(H(E_Q(\Omega), \frac{1}{k_2}) \right)^p,$$

and let $\alpha > 0$ such that $d(k_2 |u|, E_Q(\Omega)) < \alpha < 1$ and $d(k_2 |u|, E_Q(\Omega)) < 1 - \alpha < 1$.

We have $\frac{k_2}{\alpha} |u| \in K_Q(\Omega)$ and $\frac{k_2}{1-\alpha} |u| \in K_Q(\Omega)$ (see Theorem 10.1 [13]) and for $\lambda > 4k_1$ such that $\frac{4b(x)}{\lambda} \in K_R(\Omega, \rho)$, we get

$$\begin{aligned} & \int_{\Omega} R \left(\frac{|f(x, u_n) - f(x, u)|}{\lambda} \right) \rho(x) dx \\ & \leq \int_{\Omega} R \left(\frac{2b(x) + k_1 R^{-1} (\rho^{-1}(x) Q(k_2 |u_n|)) + k_1 R^{-1} (\rho^{-1}(x) Q(k_2 |u|))}{\lambda} \right) \rho(x) dx \\ & \leq \frac{1}{2} \int_{\Omega} R \left(\frac{4b(x)}{\lambda} \right) \rho(x) dx + \frac{1-\alpha}{4} \int_{\Omega} Q \left(\frac{k_2}{1-\alpha} |u_n - u| \right) \rho(x) dx \\ & \quad + \frac{\alpha}{4} \int_{\Omega} Q \left(\frac{k_2}{\alpha} |u| \right) dx + \frac{1}{4} \int_{\Omega} Q(k_2 |u|) dx. \end{aligned}$$

Since $Q(k_2 |u|) \leq Q(\frac{k_2}{\alpha} |u|)$, the last inequality becomes

$$\begin{aligned} & \int_{\Omega} R \left(\frac{|f(x, u_n) - f(x, u)|}{\lambda} \right) \rho(x) dx \\ & \leq \frac{1}{2} \int_{\Omega} R \left(\frac{4b(x)}{\lambda} \right) \rho(x) dx + \int_{\Omega} Q \left(\frac{k_2}{1-\alpha} |u_n - u| \right) dx + \int_{\Omega} Q(k_2 |u|) dx, \end{aligned}$$

which implies by using the Vitali's theorem

$$f(x, u_n) \rightarrow f(x, u) \text{ (mod) in } L_R(\Omega, \rho),$$

for a subsequence denoted again u_n (which holds for the whole sequence).

(2) Let now $u \in \left(B_{L_Q(\Omega)}(0, \frac{1}{k_2}) \right)^p$ and let $\lambda \geq 2k$ such that $\int_{\Omega} R \left(\frac{2b(x)}{\lambda} \right) \rho(x) dx \leq 1$.

By the growth condition (2.10) and the convexity of R , we get

$$\int_{\Omega} R \left(\frac{|f(x, u)|}{\lambda} \right) \rho(x) dx \leq \frac{1}{2} \int_{\Omega} R \left(\frac{2b(x)}{\lambda} \right) \rho(x) dx + \frac{1}{2} \int_{\Omega} Q(k_2 |u(x)|) dx \leq 1,$$

which implies (2).

(3) Suppose that $b(x) \in E_{R_1}(\Omega, \rho)$ with $R_1 \prec\prec R$. As in (1), since $L_R(\Omega, \rho) \subset E_{R_1}(\Omega, \rho)$, we can show that $f(x, u) \in E_{R_1}(\Omega, \rho)$ for all $u \in \left(E_Q(\Omega), \frac{1}{k_2} \right)^p$. Suppose now that

$$u_n \rightarrow u \in \left(E_Q(\Omega), \frac{1}{k_2} \right)^p \text{ in } (L_Q(\Omega))^p,$$

We shall show that

$$f(x, u_n) \rightarrow f(x, u) \text{ (mod) in } E_{R_1}(\Omega, \rho).$$

Fix $\epsilon > 0$, we have as above

$$\begin{aligned} & \int_{\Omega} R_1 \left(\frac{|f(x, u_n) - f(x, u)|}{\epsilon} \right) \rho(x) dx \leq \frac{1}{4} \int_{\Omega} R_1 \left(\frac{4b(x)}{\epsilon} \right) \rho(x) dx \\ & \quad + \frac{1}{4} \int_{\Omega} R_1 \left(\frac{4k_1}{\epsilon} R^{-1} (\rho^{-1}(x) Q(k_2 |u_n|)) \right) \rho(x) dx + \frac{1}{4} \int_{\Omega} R_1 \left(\frac{4k_1}{\epsilon} R^{-1} (\rho^{-1}(x) Q(k_2 |u|)) \right) \rho(x) dx. \end{aligned}$$

Since $R_1 \prec\prec R$, there exists K' such that $R_1(\frac{4k_1}{\epsilon}t) \leq R(t) + K'$ for all $t \geq 0$. Then, the last inequality can be written as the form

$$\begin{aligned} \int_{\Omega} R_1 \left(\frac{|f(x, u_n) - f(x, u)|}{\epsilon} \right) \rho(x) dx &\leq \frac{1}{4} \int_{\Omega} R_1 \left(\frac{4b(x)}{\epsilon} \right) \rho(x) dx + \frac{1}{4} \int_{\Omega} Q(k_2 |u_n|) dx \\ &\quad + \frac{1}{4} \int_{\Omega} Q(k_2 |u|) dx + \frac{K'}{2} \int_{\Omega} \rho(x) dx. \end{aligned}$$

As in (1) by using the Vitali's theorem, we get

$$\int_{\Omega} R_1 \left(\frac{|f(x, u_n) - f(x, u)|}{\epsilon} \right) \rho(x) dx \rightarrow 0 \text{ as } n \rightarrow \infty,$$

for a subsequence (which holds for the whole sequence). Since ϵ is arbitrary, we conclude.

3. Main results

Let Y be a closed subspace of $W^1 L_M(\Omega, \rho)$ for $\sigma(\prod L_{M, \rho}, \prod E_{\overline{M}, \rho})$ and let

$$Y_0 = Y \cap W^1 L_M(\Omega, \rho),$$

such that Y is the closure of Y_0 for $\sigma(\prod L_{M, \rho}, \prod E_{\overline{M}, \rho})$. In the next, we consider the complementary system (Y, Y_0, Z, Z_0) generated by Y i.e. Y_0^* can be identified to Z and Z_0^* can be identified to Y by the means $\langle \cdot, \cdot \rangle$. Let the mapping T (associated to the operator A) defined from $D(T) = \{u \in Y, a_0(x, u, \nabla u) \in L_{\overline{M}}(\Omega), a_i(x, u, \nabla u) \in L_{\overline{M}}(\Omega, \rho)\}$ into Z by the formula

$$a(u, v) = \int_{\Omega} a_0(x, u, \nabla u) v(x) dx + \sum_{1 \leq i \leq N} \int_{\Omega} a_i(x, u, \nabla u) \frac{\partial v(x)}{\partial x_i} \rho(x) dx \quad \forall v \in Y_0.$$

We consider the complementary system

$$(Y, Y_0, Z, Z_0) = (W_0^1 L_M(\Omega, \rho), W_0^1 E_M(\Omega, \rho), W^{-1} E_{\overline{M}}(\Omega, \rho), W^{-1} L_{\overline{M}}(\Omega, \rho)).$$

Our main results are collected in the following theorem.

Theorem 3.1. *Under the assumptions (1.2)-(1.5), (2.6)-(2.8) and $\rho(x)$ be a weight function on Ω satisfy 2.3 there exist an entropy solution u of the problem (1.1).*

3.1. Main Lemma.

Lemma 3.1. *Let u be a measurable function such that $T_k(u)$ belongs to $W_0^1 L_M(\Omega, \rho)$ for every $k > 0$. Then*

$$\int_{\Omega} a(x, u, \nabla \phi) \nabla T_k(u - \phi) dx \leq \int_{\Omega} f T_k(u - \phi) dx, \quad (3.1)$$

is equivalent to

$$\int_{\Omega} a(x, u, \nabla u) \nabla T_k(u - \phi) \rho(x) dx = \int_{\Omega} f T_k(u - \phi) dx, \quad (3.2)$$

for every $\phi \in W_0^1 L_M(\Omega, \rho)$, and for every $k > 0$.

Proof. In fact (3.2) implies (3.1) is easily proved adding and subtracting

$$\int_{\Omega} a(x, u, \nabla \phi) \nabla T_k(u - \phi) \rho(x) dx,$$

and then using assumption (1.3). Thus, it remains to prove that (3.1) implies (3.2). Let h and k be positive real numbers, let $\lambda \in]-1, 1[$ and $\Psi \in W_0^1 L_M(\Omega, \rho) \cap L^\infty(\Omega)$.

choose, $\phi = T_h(u - \lambda T_k(u - \Psi)) \in W_0^1 L_M(\Omega, \rho) \cap L^\infty(\Omega)$ as test function in (3.1), We have:

$$I_{hk} \leq J_{hk}, \quad (3.3)$$

with

$$I_{hk} = \int_{\Omega} a(x, u, \nabla T_h(u - \lambda T_k(u - \Psi))) \nabla T_k(u - T_h(u - \lambda T_k(u - \Psi))) dx,$$

and

$$J_{hk} = \int_{\Omega} f T_k(u - T_h(u - \lambda T_k(u - \Psi))) dx.$$

Put

$$A_{hk} = \{x \in \Omega, |u - T_h(u - \lambda T_k(u - \Psi))| \leq k\},$$

and

$$B_{hk} = \{x \in \Omega, |u - \lambda T_k(u - \Psi)| \leq h\}.$$

Then, we obtain

$$\begin{aligned} I_{hk} &= \int_{A_{kh} \cap B_{hk}} a(x, u, \nabla T_h(u - \lambda T_k(u - \Psi))) \nabla T_k(u - T_h(u - \lambda T_k(u - \Psi))) dx \\ &\quad + \int_{A_{kh} \cap B_{hk}^c} a(x, u, \nabla T_h(u - \lambda T_k(u - \Psi))) \nabla T_k(u - T_h(u - \lambda T_k(u - \Psi))) dx \\ &\quad + \int_{A_{kh}^c} a(x, u, \nabla T_h(u - \lambda T_k(u - \Psi))) \nabla T_k(u - T_h(u - \lambda T_k(u - \Psi))) dx. \end{aligned}$$

Since $\nabla T_k(u - T_h(u - \lambda T_k(u - \Psi)))$ is different to zero only on A_{kh} , we have

$$\int_{A_{kh}^c} a(x, u, \nabla T_h(u - \lambda T_k(u - \Psi))) \nabla T_k(u - T_h(u - \lambda T_k(u - \Psi))) dx = 0. \quad (3.4)$$

Moreover, if $x \in B_{hk}^c$, we have $\nabla T_h(u - \lambda T_k(u - \Psi)) = 0$ and using (1.4), we deduce that,

$$\begin{aligned} &\int_{A_{kh} \cap B_{hk}^c} a(x, u, \nabla T_h(u - \lambda T_k(u - \Psi))) \nabla T_k(u - T_h(u - \lambda T_k(u - \Psi))) dx \\ &= \int_{A_{kh} \cap B_{hk}^c} a(x, u, 0) \nabla T_k(u - T_h(u - \lambda T_k(u - \Psi))) dx = 0. \end{aligned} \quad (3.5)$$

From (3.4) and (3.5), we obtain

$$I_{hk} = \int_{A_{kh} \cap B_{hk}} a(x, u, \nabla T_h(u - \lambda T_k(u - \Psi))) \nabla T_k(u - T_h(u - \lambda T_k(u - \Psi))) dx.$$

Letting $h \rightarrow +\infty, |\lambda| \leq 1$, we have

$$A_{kh} \rightarrow \{x, |\lambda| |T_k(u - \Psi)| \leq h\} = \Omega, \quad (3.6)$$

$$B_{hk} \rightarrow \Omega \text{ which implies } A_{kh} \cap B_{hk} \rightarrow \Omega. \quad (3.7)$$

Which and using Lebesgue theorem, we conclude that

$$\begin{aligned} &\lim_{h \rightarrow +\infty} \int_{A_{kh} \cap B_{hk}} a(x, u, \nabla T_h(u - \lambda T_k(u - \Psi))) \nabla T_k(u - T_h(u - \lambda T_k(u - \Psi))) dx \\ &= \lambda \int_{\Omega} a(x, u, \nabla(u - \lambda T_k(u - \Psi))) \nabla T_k(u - \Psi) dx. \end{aligned} \quad (3.8)$$

thus implies that,

$$\lim_{h \rightarrow +\infty} I_{hk} = \lambda \int_{\Omega} a(x, u, \nabla(u - \lambda T_k(u - \Psi))) \nabla T_k(u - \Psi) dx. \quad (3.9)$$

On the other hand, we have,

$$J_{hk} = \int_{\Omega} f T_k(u - T_h(u - \lambda T_k(u - \Psi))) dx.$$

Then

$$\lim_{h \rightarrow +\infty} \int_{\Omega} f T_k(u - T_h(u - \lambda T_k(u - \Psi))) dx = \lambda \int_{\Omega} f T_k(u - \Psi) dx, \quad (3.10)$$

i.e.,

$$\lim_{h \rightarrow +\infty} J_{hk} = \lambda \int_{\Omega} f T_k(u - \Psi) dx. \quad (3.11)$$

Together (3.9), (3.11) and passing to the limit in (3.3), we obtain,

$$\lambda \left(\int_{\Omega} a(x, u, \nabla(u - \lambda T_k(u - \Psi))) \nabla T_k(u - \Psi) dx \right) \leq \lambda \left(\int_{\Omega} f T_k(u - \Psi) dx \right)$$

for every $\Psi \in W_0^1 L_M(\Omega, \rho) \cap L^\infty(\Omega)$, and for every $k > 0$. Choosing $\lambda > 0$ dividing by λ , and then letting λ tend to zero, we obtain

$$\int_{\Omega} a(x, u, \nabla u) \nabla T_k(u - \Psi) dx \leq \int_{\Omega} f T_k(u - \Psi) dx. \quad (3.12)$$

for $\lambda < 0$, dividing by λ , and then letting λ tend to zero, we obtain

$$\int_{\Omega} a(x, u, \nabla u) \nabla T_k(u - \Psi) dx \geq \int_{\Omega} f T_k(u - \Psi) dx. \quad (3.13)$$

Combining (3.12) and (3.13), we conclude the following equality :

$$\int_{\Omega} a(x, u, \nabla u) \nabla T_k(u - \Psi) dx = \int_{\Omega} f T_k(u - \Psi) dx. \quad (3.14)$$

This completes the proof of Lemma 3.1.

3.2. Proof of Theorem 3.1.

3.2.1. Approximate problem and a priori estimate. For $n \in \mathbb{N}$, define $f_n := T_n(f)$. Let u_n be solution in $W_0^1 L_\varphi(\Omega)$ of the problem

$$\begin{cases} -\operatorname{div}(a(x, u_n, \nabla u_n)) = f_n & \text{in } \Omega \\ u_n = 0 & \text{on } \partial\Omega, \end{cases} \quad (3.15)$$

which exists thanks to [14]. Choosing $T_k(u_n)$ as test function in (3.15), we have

$$\int_{\Omega} a(x, u_n, \nabla u_n) \nabla T_k(u_n) dx = \int_{\Omega} f_n T_k(u_n) dx,$$

using $\nabla T_k(u_n) = \nabla u_{n\chi_{\{|u_n| \leq k\}}}$ and thanks to assumption (1.4), we obtain

$$\int_{\Omega} a(x, u_n, \nabla u_n) \nabla T_k(u_n) dx \geq \int_{\Omega} M(\lambda_1 |\nabla T_k(u_n)|) dx,$$

then

$$\int_{\Omega} \rho(x) M(\lambda_1 |\nabla T_k(u_n)|) dx \leq k \|f\|_{L^1(\Omega)}. \quad (3.16)$$

Then

$$\int_{\Omega} \rho(x) M(\lambda_1 |\nabla T_k(u_n)|) dx \leq C_1 k, \quad (3.17)$$

where C_1 is a constant independently of n .

3.2.2. Locally convergence of u_n in measure. Taking $\frac{1}{\lambda}|T_k(u_n)|$ in (3.15) and using (3.17), one has

$$\int_{\Omega} \rho(x) M(\lambda_1 \frac{|\nabla T_k(u_n)|}{\lambda}) dx \leq \int_{\Omega} \rho(x) M(\lambda_1 |\nabla T_k(u_n)|) dx \leq C_1 k. \quad (3.18)$$

Then we deduce by using (3.18), that

$$\begin{aligned} \text{meas}\{|u_n| > k\} &\leq \frac{1}{\inf_k M(\frac{k}{\lambda})} \int_{\{|u_n| > k\}} M(\frac{|u_n(x)|}{\lambda}) dx \\ &\leq \frac{1}{\inf_k M(\frac{k}{\lambda})} \int_{\Omega} M(\frac{1}{\lambda} |T_k(u_n)|) dx \\ &\leq \frac{C_1 k}{\inf_k M(\frac{k}{\lambda})} \quad \forall n, \quad \forall k \geq 0. \end{aligned} \quad (3.19)$$

For any $\beta > 0$, we have

$$\text{meas}\{|u_n - u_m| > \beta\} \leq \text{meas}\{|u_n| > k\} + \text{meas}\{|u_m| > k\} + \text{meas}\{|T_k(u_n) - T_k(u_m)| > \beta\},$$

and so that

$$\text{meas}\{|u_n - u_m| > \beta\} \leq \frac{2C_1 k}{\inf_k M(\frac{k}{\lambda})} + \text{meas}\{|T_k(u_n) - T_k(u_m)| > \beta\}. \quad (3.20)$$

By using (3.17) and Poincaré inequality in weighted Orlicz-Sobolev spaces, we deduce that $(T_k(u_n))$ is bounded in $W_0^1 L_M(\Omega, \rho)$, and then there exists $\omega_k \in W_0^1 L_M(\Omega, \rho)$ such that $T_k(u_n) \rightharpoonup \omega_k$ weakly in $W_0^1 L_M(\Omega, \rho)$ for $\sigma(\Pi L_M, \Pi E_{\overline{M}})$; strongly in $E_{\overline{M}}(\Omega, \rho)$ and a.e. in Ω .

Consequently, we can assume that $(T_k(u_n))_n$ is a Cauchy sequence in measure in Ω .

Let $\varepsilon > 0$, then by (3.20) and the fact that $\frac{2C_1 k}{\inf_k M(\frac{k}{\lambda})} \rightarrow 0$ as $k \rightarrow +\infty$ there exists some $k = k(\varepsilon) > 0$ such that

$$\text{meas}\{|u_n - u_m| > \lambda\} < \varepsilon, \quad \text{for all } n, m \geq h_0(k(\varepsilon), \lambda).$$

This proves that u_n is a Cauchy sequence in measure, thus, u_n converges almost everywhere to some measurable function u . Finally, there exist a subsequence of $\{u_n\}_n$, still indexed by n , and a function $u \in W_0^1 L_M(\Omega, \rho)$ such that

$$\begin{cases} u_n \rightharpoonup u & \text{weakly in } W_0^1 L_M(\Omega, \rho) \text{ for } \sigma(\Pi L_M, \Pi E_{\overline{M}}) \\ u_n \rightarrow u & \text{strongly in } E_M(\Omega, \rho) \text{ and a.e. in } \Omega. \end{cases} \quad (3.21)$$

3.2.3. An intermediate Inequality. In this step, we shall prove that for $\phi \in W_0^1 L_M(\Omega, \rho) \cap L^\infty(\Omega)$, we have

$$\int_{\Omega} a(x, u_n, \nabla \phi) \nabla T_k(u_n - \phi) dx \leq \int_{\Omega} f_n T_k(u_n - \phi) dx. \quad (3.22)$$

We choose now $T_k(u_n - \phi)$ as test function in (3.15), with ϕ in $W_0^1 L_M(\Omega, \rho) \cap L^\infty(\Omega)$, we obtain

$$\int_{\Omega} a(x, u_n, \nabla u_n) \nabla T_k(u_n - \phi) dx = \int_{\Omega} f_n T_k(u_n - \phi) dx. \quad (3.23)$$

Adding and subtracting the term $\int_{\Omega} a(x, u_n, \nabla \phi) \nabla T_k(u_n - \phi) dx$ i.e.,

$$\begin{aligned} \int_{\Omega} a(x, u_n, \nabla u_n) \nabla T_k(u_n - \phi) dx + \int_{\Omega} a(x, u_n, \nabla \phi) \nabla T_k(u_n - \phi) dx \\ - \int_{\Omega} a(x, u_n, \nabla \phi) \nabla T_k(u_n - \phi) dx = \int_{\Omega} f_n T_k(u_n - \phi) dx. \end{aligned} \quad (3.24)$$

Thanks to assumption (1.3) and the definition of truncation function, we have

$$\int_{\Omega} (a(x, u_n, \nabla u_n) - a(x, u_n, \nabla \phi)) \nabla T_k(u_n - \phi) dx \geq 0. \quad (3.25)$$

Combining (3.23) and (3.25), we obtain (3.22).

3.2.4. Passing to the limit. We shall prove that for $\phi \in W_0^1 L_M(\Omega, \rho) \cap L^\infty(\Omega)$, we have

$$\int_{\Omega} a(x, u, \nabla \phi) \nabla T_k(u - \phi) dx \leq \int_{\Omega} f T_k(u - \phi) dx.$$

Firstly, we claim that

$$\int_{\Omega} a(x, u_n, \nabla \phi) \nabla T_k(u_n - \phi) dx \rightarrow \int_{\Omega} a(x, u, \nabla \phi) \nabla T_k(u - \phi) dx \text{ as } n \rightarrow +\infty.$$

Since $T_M(u_n) \rightharpoonup T_M(u)$ weakly in $W_0^1 L_M(\Omega, \rho)$, with $M = k + \|\phi\|_\infty$, then

$$T_k(u_n - \phi) \rightharpoonup T_k(u - \phi) \text{ in } W_0^1 L_M(\Omega, \rho), \quad (3.26)$$

which gives

$$\frac{\partial T_k}{\partial x_i}(u_n - \phi) \rightharpoonup \frac{\partial T_k}{\partial x_i}(u - \phi) \text{ weakly in } L_M(\Omega, \rho) \quad \forall i = 1, \dots, N. \quad (3.27)$$

Show that

$$a(x, T_M(u_n), \nabla \phi) \rightarrow a(x, T_M(u), \nabla \phi) \text{ strongly in } (L_{\overline{M}}(\Omega))^N.$$

Thanks to assumption (1.2), we obtain

$$|a_i(x, T_M(u_n), \nabla \phi)| \leq |\phi_i(x)| + K_i \overline{P}^{-1}(\rho^{-1}(x) M(c_2 |T_M(u_n)|)) + K_i \overline{M}^{-1} M(c_1 |\nabla \phi|),$$

with β and μ are positive constants. Since $T_M(u_n) \rightharpoonup T_M(u)$ weakly in $W_0^1 L_M(\Omega, \rho)$ and $W_0^1 L_M(\Omega, \rho) \hookrightarrow L_{\overline{M}}(\Omega, \rho)$, then $T_M(u_n) \rightarrow T_M(u)$ strongly in $L_M(\Omega, \rho)$ and a.e. in Ω , hence

$$|a(x, T_M(u_n), \nabla \phi)| \rightarrow |a(x, T_M(u), \nabla \phi)| \text{ a.e. in } \Omega.$$

and

$$|\phi_i(x)| + K_i \overline{P}^{-1}(\rho^{-1}(x) M(c_2 |T_M(u_n)|)) + K_i \overline{M}^{-1} M(c_1 |\nabla \phi|) \rightarrow$$

$$|\phi_i(x)| + K_i \overline{P}^{-1}(\rho^{-1}(x) M(c_2 |T_M(u)|)) + K_i \overline{M}^{-1} M(c_1 |\nabla \phi|),$$

a.e. in Ω . Then, By Vitali's theorem, we deduce that

$$a(x, T_M(u_n), \nabla \phi) \rightarrow a(x, T_M(u), \nabla \phi) \text{ strongly in } (L_{\overline{M}}(\Omega, \rho))^N, \text{ as } n \rightarrow \infty. \quad (3.28)$$

Combining (3.27) and (3.28), we obtain

$$\int_{\Omega} a(x, u_n, \nabla \phi) \nabla T_k(u_n - \phi) dx \rightarrow \int_{\Omega} a(x, u, \nabla \phi) \nabla T_k(u - \phi) dx \text{ as } n \rightarrow +\infty. \quad (3.29)$$

Secondly, we show that

$$\int_{\Omega} f_n T_k(u_n - \phi) dx \rightarrow \int_{\Omega} f T_k(u - \phi) dx. \quad (3.30)$$

We have $f_n T_k(u_n - \phi) \rightarrow f T_k(u - \phi)$ a.e. in Ω and $|f T_k(u_n - \phi)| \leq k|f|$, then by using Vitali's theorem, we obtain (3.30). Thanks to (3.29) and (3.30) allow to pass to the limit in the inequality (3.22), so that $\forall \phi \in W_0^1 L_M(\Omega, \rho) \cap L^\infty(\Omega)$, we deduce

$$\int_{\Omega} a(x, u, \nabla \phi) \nabla T_k(u - \phi) dx \leq \int_{\Omega} f T_k(u - \phi) dx.$$

In view of main Lemma, we can deduce that u is an entropy solution of the problem (1.1). This completes the proof of Theorem 3.1.

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